EUFAR FP7 HyQuaPro (JRA-2) Report on Quality Layers for VITO, DLR, INTO and PML

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EUFAR FP7

JRA2 - HYQUAPRO

- V0.9-

DJ2.2.2 – Quality Layers for VITO, DLR, INTA, and PML

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2 Introduction

This document is produced under the EUFAR project (Contract number 227159) and constitutes deliverable number DJ2.2.2.

2.1 General

One of the main objectives of EUFAR JRA2 is *"to develop quality indicators and quality layers for airborne hyperspectral imagery"*.

Therefore generic quality indicators and quality layers for airborne hyperspectral images (based on sensor and scene characteristics) will be developed. Sensor characteristics, sensor calibration, data characterisation, sensor performance during acquisition, external conditions during acquisition, quality of auxiliary data used for the processing will be translated into generic quality indicators and quality layers (DJ2.2.1). Starting from the generic quality layers, these will be adjusted ("personalized") for the different processing facilities involved since different sensors, software, auxiliary data and processing methods are used at the different processing facilities (DJ2.2.2, DJ2.2.3). After adjustment of the quality layers, the layers will be integrated in the respective processing facilities. In addition the full-error propagation concept (Task 1) will be applied.

2.2 Scope

The scope of this document is the documentation of the algorithms (ATBD) and the implementation scheme for the selected and agreed Quality Indicators. Within DJ2.2.2, this is documented for the DLR, INTA, PML and VITO PAFs for airborne hyperspectral data; for the PAFs at USBE, TAU and FUB, documentation will be included within DJ2.2.3.

2.3 Relationship with other WPs and Tasks

2.3.1 Relationships within WP25

This deliverable (DJ2.2.2) together with DJ2.2.3 constitutes the implementation of the selected common Quality Indicators documented in DJ2.2.1, thus finalizing Task 2 of EUFAR JRA2. In Task 3 the QIs are then tested and validated. Task 4, (development of advanced soil and water products) will incorporate QIs within the processing scheme. During the selection process within Task 2, the results of Task 1 (uncertainty propagation for the processing of hyperspectral data) are taken into account.

2.3.2 Relationships with other WPs

The Networking Activity "Standards and Protocols" (N6SP) aims for harmonization of different processes and documentation concerning the acquired data within EUFAR. Therefore, the development of common quality layers will also be in the interest of N6SP. The proposal of common protocols (DN6.1.3) will be in agreement with JRA2. JRA2 provided input to the Basic Glossary developed in the frame of DN6.1.1 of N6SP. On the other hand DN6.1.1 Basic Glossary will be the baseline for future JRA2 related reports and publications.
EUFAR's Networking Activity "DataBase" (N7DB) uses metadata as input for the common Data Base. N7DB will be informed of the development of the different quality layers and

indicators. JRA2 PAFs participating in the Transnational Access activity provided input related to hyperspectral data archiving for the concept development of the "Database".

2.4 Process overview

The following table outlines the contribution of the partners involved. The task leader DLR is indicated in bold and is responsible for the timely completion and quality of the deliverable.

	VITO	**DLR**	INTA	FUB	UZH	TAU	PML	USBE
Selection of Common Algorithms	x	x	x	x	x	x	x	x
Description of selected Common Algorithms	x	x			x			
Description of implementation @ PAFs	x	x	x	*	x	*	x	*
Documentation and finalization of DJ2.2.2		x						
Final review of DJ2.2.2	x							

x: documented in DJ2.2.2
*: documented in DJ2.2.3

2.5 Document structure

Chapter 1	provides the Table of Contents.
Chapter 2	describes the objectives and the relationships with other WPs, tasks and the process used to achieve the objectives.
Chapter 3	gives an update on Data Descriptors and Quality Layers.
Chapter 4	presents the User Requirements related to the harmonized quality indicators, quality layers and data descriptors
Chapter 5	introduces the Software Requirements related to these User Requirements
Chapter 6	presents the selected Common Algorithms
Chapters 7-10	describe the implementation of the QIs at the DLR, INTA, PML and VITO/UZH PAFs as well as recent developments in the PAF
Chapter 11	Provides an outlook on testing & validation (Task 3)
Chapter 12	References
Chapter 13 – Annex	lists the various Product Level definitions.
Chapter 14 – Annex	Provides the Software Requirements of all PAFs

2.6 Terms and abbreviations

ATBD	Algorithm Theoretical Basis Document
GPS	Global Positioning System
IMU	Inertial Measurement Unit
PAF	Processing and Archiving Facility
QI	Quality Indicator
QL	Quality Layer
SW	Software

For a full definition of terms, please refer to the EUFAR Basic Glossary which is available on the EUFAR webpage, or within EUFAR N6SP DN6.1.1.

3 Updates on Data Descriptors and Quality Layers

Within the previous deliverable DJ221, an outlook on the implementation phase was provided (DJ222, Chapter 5). In the following, these pending issues are now finalized based on the decisions made during the JRA2 meetings.

3.1 Harmonization of algorithms

Within this document, the recommended Common Algorithms as well as the PAF-specific approaches are documented. Therefore this document can be used as an ATBD.

3.2 Harmonization of appearance

The common nomenclature of Data Descriptors is in accordance with INSPIRE and ISO 19115 guidelines as documented in Chapter 4.

Within EUFAR JRA2, it is recommended to use the self-contained format HDF5. Also, N7DB requests data in hdf-format. As it is a binary container format, image data as well as metadata (Quality Layers, Data Descriptors etc.) can be included in a single file.

Note that if desired by the PAF or the end user, it is also possible to provide the hyperspectral image data and the Quality Layers in well-established data formats like ENVI. For the Data Descriptors, formats such as plain ASCII are also possible.

3.3 Thresholding

As any rating of data quality (e.g., “nominal performance”, “reduced accuracy”) should be based on objective measures, fixed thresholds for such rating must be applied. But as different sensors and processing chains are included in EUFAR, these thresholds are highly PAF-specific.
As agreed during the JRA2 meetings, the baseline is that all provided data has to be well documented. This is especially true in case of errors in the data, or in case of a reduced performance of the sensor, GPS or IMU.
For a quality rating, it is up to the PAFs if such an additional measure is provided or not. Therefore details can be found in the PAF-specific chapters.

3.4 QL dimensionality

When dealing with hyperspectral datasets, the dimension can be addressed as a 3-dimensional matrix (“data cube”) with the length of the flight line in pixels as {L}, the number of image columns (i.e. the number of cross-track pixels) {C}, and the number of spectral bands as {B} dimension. According to that, reduced image quality or defects in the hyperspectral data (e.g., saturation of a certain pixel in a certain band) can be represented by flags in {L,C,B}.
Thus, if one wants to flag pixel-specific (i.e., specify a flag in line / column / band), one would have a 3-D datacube with the same size as the original image. As there are multiple quality-related parameters, a 4th “thematic” dimension {T} is added.

But this is not feasible for the user dealing with non-intuitive 4-dimensional data, nor is it reasonable to provide quality layers with file sizes magnitudes larger than the image data itself. Therefore, there is a strong need for simplification.

For the Quality Flags of EUFAR JRA2 the spectral dimension is simplified by aggregating this information resulting in a {L,C,T} dataset. This approach has the advantage that the various QIs can be addressed simultaneously.

3.5 QL geometry

As the georectification of a Quality Layer is not straightforward at all (because of a meaningful interpolation during rectification), the most accurate way is to provide the Quality Layers in the geometry in which they were derived.

One recommended way is that –if possible- all QLs will be delivered in the original geometry (i.e., not georectified). By distributing the geolocation as GLT file, the end user can link the QLs to the image pixels while avoiding the interpolation problem.

4 Quality Layers / Data Descriptors – User Requirements

In the following, a brief summary on the Quality Layers and Data Descriptors as described in DJ2.2.1 will be given. Note that during the JRA2 Meeting 4 in May 2010 and Meeting 5 in October 2010, this list of parameters was updated.

Following the ECSS nomenclature, these Data QC Parameters are then treated as "User Requirements" for the implementation, testing and validation.

4.1 Quality Layers

4.1.1 Sensor calibration / Data artefacts

Quality Layers:

1. Aggregated bad pixel mask ("not corrected"), which includes
   - Uncorrected dead pixels on detector
   - Negative radiance / reflectance values
   - Data artefacts
2. Aggregated interpolated pixel mask ("corrected")
3. Saturated pixel / overflow

4.1.2 GPS / IMU related errors / Geometric correction

Quality Layers:

4. Problems with position information and attitude information
5. Interpolated position / attitude information

4.1.3 Atm. correction / Atm. conditions

Quality Layers:

6. Cloud mask
7. Cloud shadow mask (if available)
8. Haze mask (if available)

4.1.4 Terrain related

9. Critical local viewing and illumination geometry

4.2 Additional Data Layers (informative)

If available, the following data layers should be provided as additional information layers. In particular, the characterization of the atmospheric conditions during the overflight (i.e., water vapor content and overall visibility) is helpful when assessing the overall data quality.

10. Water vapor map
11. AOT / Visibility map
12. Scan angle file
13. DEM (if disposable)

If no HDF5 container format is used, these layers can be added to the QL file, or distributed as additional files in an established file format such as ENVI.

4.3 Data Descriptors

All Data Descriptors could be implemented into an INSPIRE conform metadata file. As an example, the DLR xml metadata file - which is INSPIRE and ISO 19115 conform - can serve as a guideline. Therefore a complete metadata file is attached to this document. Note that this xml example is tailored to DLR's multi-mission infrastructure DIMS, and therefore not all parts are of relevance within the EUFAR context.
Note that as agreed during the JRA2 meetings, the same information could also be provided in a plain ASCII file instead of an embedded xml layer in HDF5.

In the following, this file serves as guideline for the implementation of the different data descriptors into a metadata file. The different fonts correspond to

1. *INSPIRE metadata elements: Italic / Times*
2. *INSPIRE or ISO 19115 metadata elements implemented in xml metadata file: Italic / Courier*
3. Data descriptors implemented in xml metadata file (non ISO): Courier

Example:
(26) Processing level → Number and name of data descriptor as agreed within HYQUAPRO
- *Part B 6 Quality and Validity, Part B 6.1 Lineage* → corresponding INSPIRE metadata element…
- *<feature key="processStep">* → …implemented in metadata file
    - *<feature key="processingInformation">*
- *ISO-Metadata*
- *<feature key="contentInfo">* → Data descriptor implemented as ISO 19115 metadata
    - *<feature key="processingLevelCode">*
- Level 1, Level 2geo, Level 2atm, Level2 (see fig. at the end of this document for specifications) → content explanation as agreed within HYQUAPRO
- <feature key="processingOptions"> → Data descriptor implemented outside the INSPIRE/ISO-metadata entity

Remark: If the INSPIRE metadata element is highlighted, the data descriptor has not been added to the INSPIRE metadata, but could be within the proposed category.

4.3.1 General information

1. Provider and contact information
    - *Part B 9.1 Responsible party, Part B 9.2. Responsible party role*
    - *<feature key="pointOfContact">*
        - *<feature key="role">*
    - Provider name
    - Organisation name
    - Point of contact and role (e.g., campaign manager)
    - Phone number
    - Fax number
    - Address
    - E-mail
    - Web page
    - Other Project scientists
2. Customer information
    - *Part B 9.1 Responsible party, Part B 9.2 Responsible party role*
    - *<feature key="pointOfContact">*
        - *<feature key="role">*
    - P.I. name
    - Organization name

- <feature key="principalInvestigator">

3. File name / unique ID
   - *Part B 1.5. Unique resource identifier*
   - *<feature key="fileIdentifier">*
   - N7-DB file name specification
4. Campaign name
   - *Part B 1.1. Resource title*
   - *<feature key="title">*
   - EUFAR project acronym
   - <feature key="projectId">
5. Site name
   - *Part B 4 Geographic location, Part B 4.1 Geographic bounding box*
   - *<feature key="extend">*
     - *<feature key="description">*
     - *<feature key="geographicElement">*
       - *<feature key="boundingPolygon">*
   - Country
   - Province/Region
   - Local name
   - Map of general area (e.g. kml-file) DD
6. Basic sensor characteristics used
   - *Part B 1 Identification*
   - Scan principle
   - Spectral range
   - Spectral bandwidth
   - No. of bands / binning (if applicable)
   - Total Field of View (FOV)
   - Inst. Field of View (IFOV)
   - Pixels per scanline
   - Radiometric resolution / quantization
   - <feature key="sensorSpecifics">
     - <feature key="type">
     - <feature key="pixelsInLine">
     - <feature key="maximumScanAngle">
   - <feature key="bandParameters">
     - <feature key="centerWavelength">
     - <feature key="fullWidthHalfMax">
     - <feature key="fieldOfView">
     - <feature key="instantaneousFieldOfView">
7. File name- raw data
   - *Part B 6 Quality and Validity, Part B 6.1 Lineage*
   - *<feature key="lineage">*
     - *<feature key="source">*
       - *<feature key="sourceCitation">*
   - see File name / unique ID
   - Original raw data name
8. File name - quality layers
   - *Part B 6 Quality and Validity, Part B 6.1 Lineage*
   - see File name / unique ID
   - <component>
   - <type>AIROS.L2-QAL</type
   - </component>

4.3.2 (Laboratory) Calibration information

9. Calibration laboratory
    - *Part B 6 Quality and Validity, Part B 6.1 Lineage*
    - e.g. CHB, DLR Oberpfaffenhofen, Germany
    - `<feature key="calibrationLaboratory">`
10. Date of radiometric calibration
    - *Part B 6 Quality and Validity, Part B 6.1 Lineage*
    - DD.MM.YYYY
    - `<feature key="dateOfCalibrationFile">`
11. Date of spectral calibration
    - *Part B 6 Quality and Validity, Part B 6.1 Lineage*
    - DD.MM.YYYY
    - `<feature key="dateOfCalibrationFile">`
12. Radiometric calibration file used
    - *Part B 6 Quality and Validity, Part B 6.1 Lineage*
    - filename
    - `<feature key="calibrationFilename">`
13. Radiance unit + scaling
    - *Part B 6 Quality and Validity, Part B 6.1 Lineage*
    - e.g. W / m² sr µm
    - `<feature key="scalingFactor">`

4.3.3 Acquisition information

14. Date & start/end time of acquisition
    - *Part B 5.1. Temporal extent*
    - *`<feature key="temporalElement">`*
    - DD.MM.YYYY, hh:mm-hh:mm (UTC)
    - `<feature key="utcStartTime">`
    - `<feature key="utcStopTime">`
15. Platform
    - *Part B 1 Identification*
    - *ISO-Metadata*
    - *`<feature key="acquisitionInfo">`*
        i. *`<feature key="platform">`*
    - Aircraft call sign (see EUFAR TA list)
16. Sensor
    - *Part B 1 Identification*
    - *ISO-Metadata*
    - *`<feature key="acquisitionInfo">`*
        - *`<feature key="instrument">`*
    - e.g. APEX (see EUFAR TA list)
17. GPS/IMU
    - *Part B 1 Identification*
    - e.g. Applanix POS AV 410, DLR Oberpfaffenhofen, Germany
    - `<feature key="navigationUnit">`
18. Number of spectral bands (spectral mode)
    - *Part B 1 Identification*
    - e.g. mode 1 (free text)
    - `<feature key="sensorParameters">`
        - `<feature key="configuration">`
19. Spatial resolution (across track)
    - *Part B 6.2 Spatial resolution*
    - *`<feature key="spatialResolution">`*

- Statement in meter
- `<feature key="angularSamplingDistance">`
- `<feature key="groundSamplingDistance">`

20. Spatial resolution (along track)
    - *Part B 6.2 Spatial resolution*
    - *`<feature key="spatialResolution">`*
    - Statement in meter
    - `<feature key="angularSamplingDistance">`
    - `<feature key="groundSamplingDistance">`
21. Frame rate / integration time
    - *Part B 1 Identification*
    - Statement in Hz
    - `<feature key="sensorParameters">`
        - `<feature key="scanFrequency">`
22. Overall heading
    - *Part B 1 Identification*
    - Statement in degree (range 0-360, west = 270°)
    - `<feature key="angleToTrueNorth">`
23. Overall altitude ASL
    - *Part B 1 Identification*
    - flying altitude above sea level in meter
    - `<feature key="altitudeAboveSeaLevel">`
24. Solar zenith / azimuth during acquisition
    - *Part B 1 Identification*
    - Solar Zenith: range 0-90, sunrise = 90°; Solar azimuth: range 0-360, North = 0°, East = 90°,…
    - `<feature key="solarAzimuth">`
    - `<feature key="solarZenith">`
25. Report on anomalies in data acquisition
    - *Part B 1 Identification*
    - *ISO-Metadata*
    - *`<feature key="acquisitionInfo">`*
        - *`<feature key="description">`*
    - comment (free text)
    - `<feature key="cloudCover">`

4.3.4 Processing information

26. Processing level
    - *Part B 6 Quality and Validity, Part B 6.1 Lineage*
    - *`<feature key="processStep">`*
        - *`<feature key="processingInformation">`*
    - *ISO-Metadata*
    - *`<feature key="contentInfo">`*
        - *`<feature key="processingLevelCode">`*
    - Level 1, Level 2geo, Level 2atm, Level2 (see fig. at the end of this document for specifications)
    - `<feature key="processingOptions">`
27. Processor ID, SW names & versions
    - *Part B 6 Quality and Validity, Part B 6.1 Lineage*
    - e.g. dims_ares version 1.2, DLR PAF
    - `<feature key="softwareVersion">`
28. Date & time of processing
    - *Part B 6 Quality and Validity, Part B 6.1 Lineage*
    - *`<feature key="processStep">`*

   - <feature key="dateTime">
 - DD.MM.YYYY, hh:mm (UTC)

29. Synchronization problem (new)
    - *Part B 6 Quality and Validity, Part B 6.1 Lineage*
    - <feature key="synchronizationProblem"
30. Method of interpolation (new)
    - *Free text within: Part B 6 Quality and Validity, Part B 6.1 Lineage*
    - e.g. Nearest Neighbour (free text)
    - <feature key="resampling">
31. Confidence in atmospheric correction from model itself (new – formerly pixel flag for atm. correction failure by TUB)
    - *Part B 6 Quality and Validity, Part B 6.1 Lineage*
    - Remark in MOMO / ATCOR / … log file
    - <feature key="confidence">
        - <feature key="model">
32. Confidence in atmospheric correction due to comparison with ground measurements (new)
    - *Part B 6 Quality and Validity, Part B 6.1 Lineage*
    - available ground measurements: sensor, date, file,…(free text)
    - <feature key="confidence">
        - <feature key="groundMeasurements">
33. Information on DEM (e.g. resolution, accuracy,…) used for processing (new)
    - *Part B 6 Quality and Validity, Part B 6.1 Lineage*
    - source, resolution, accuracy, …
    - <feature key="dem">
34. Critical BRDF geometry (new)
    - *Part B 6 Quality and Validity, Part B 6.1 Lineage*
    - remark in ATCOR log file
    - <feature key="brdfCorrection">
35. Pixels affected by saturation in spatial/spectral neighbourhood (AISA problem) (new)
    - *Part B 6 Quality and Validity, Part B 6.1 Lineage*
    - comment (free text)
    - <feature key="saturation">
        - <feature key="affectedPixels">

4.4 List of User Requirements

Based on the Quality Indicators described and agreed in DJ2.2.1, and on the progress made in the following JRA2 meetings, common User Requirements were defined for each of the 9 Quality Layers. For the 35 Data Descriptors only joint User Requirements are defined. An overview is given in **Error! Reference source not found.** below.

ID	Origin Document	Origin Doc Section	Requirement description
UR_001	DJ221	2.1	The set of QIs is composed of a subset of QIs that are common for every PAF and a subset that is PAF specific. For the PAF specific QIs, an ATBD shall be available.
UR_002	DJ221	2.1	The set of PAF-common QIs are produced and formatted irrespective of the sensor system (HyMap, APEX, CASI, AHS, …).
UR_003	DJ221	3.1	Every QI is based on a quantitative assessment and the assessment method shall be traceable to an agreed reference of measurement standard (ideally SI).
UR_004	DJ221	3.1	The set of PAF-common QI shall be homogenized within all EUFAR PAFs.
UR_005	DJ221	3.1	For every QI an ATBD (Algorithm Theoretical Base Documentation) shall be

			available.
UR_006	DJ221	3.3	EUFAR PAF product levels are: L0 (raw data + raw metadata), L1, L2geo, L2atm, L2 atm+geo.
UR_007	DJ221	4.1.1	For every product level (L0, L1, L2) a text report shall contain the Common Data Descriptor QIs as specified within DJ2.2.2 and DJ2.2.3.
UR_008	DJ221	4.1.2	Quality Layer QI: Aggregated interpolated pixel mask
UR_009	DJ221	4.1.2	Quality Layer QI: Aggregated bad pixel mask
UR_010	DJ221	4.1.2	Quality Layer QI: Saturated pixel mask
UR_011	-	-	[Obsolete – ID kept for consistency]
UR_012	DJ221	4.1.2	Quality Layer QI: Mask: problems with position / attitude information
UR_013	-	-	[Obsolete – ID kept for consistency]
UR_014	DJ221	4.1.2	Quality Layer QI: Mask: interpolated position / attitude information
UR_015	-	-	[Obsolete – ID kept for consistency]
UR_016	DJ221	4.1.2	Quality Layer QI: Cloud mask
UR_017	DJ221	4.1.2	Quality Layer QI: Cloud shadow mask
UR_018	DJ221	4.1.2	Quality Layer QI: Haze mask
UR_019	DJ221	4.1.2	Quality Layer QI: Critical local viewing and illumination geometry
UR_020	DJ221	5.2.3	For non-georeferenced Quality Layer QIs that are provided in association with an L2 product, a separate geo-location file shall be provided

Table 1: Overview of common user requirements

5 Quality Layer Implementation – Software Requirements

Each of the common User Requirements was translated into Software Requirements. The various requirements types are listed below. For most of the PAFs only Software Requirements of the red requirement types are defined. Examples of the red requirement types can be found below based on the VITO description. The URD and SRD is crucial as during the validation phase tests are performed against the URD and SRD. The SRD's of the various PAFs can be found in Annex B.

Requirement type	Example from VITO PAF
Functional	A module shall be designed and developed to automatically generate a haze mask. The output shall be a probability or likelihood of being haze contaminated (no hard classification). The input can be one of the following: digital number, at-sensor radiance or at-surface reflectance or at-surface radiance.
Performance	The haze detection algorithm shall reach a completeness of better than 90%
Interface	The information to create the text file containing the Common Data Descriptor QIs shall be stored in the PAF database system.
Operational	Upon new incoming data, an operator is responsible to update the database tables used to poll the Common Data Descriptor QIs from.
Resources	
Design & Implementation	Quality Layer QI: Aggregated bad pixel mask (Pixel, L0, L1, L2). As part of the L0 to L1 calibration workflow and for pushbrooms: - A map shall be produced (if data available) indicating which of the defective CCD/CMOS pixels were NOT interpolated and thus remain in the status "bad". This shall be reported in the VITO "campaign report" as described in the SRD items in response of UR_001. The map of defective pixels is in CCD/CMOS geometry.
Security & Privacy	Sensor system information or image metadata that is not allowed for public dissemination shall be flagged in the PAF database system.
Portability	
Software quality	Missing QIs which are part of the Common Data Descriptor QIs, shall be marked as "No Information Available" in the text report.
Software reliability	
Software Maintainability	
Software Safety	
Software Configuration & Delivery	The module for generating the saturated pixel map shall be integrated in the L0 to L1 workflow, where it can be optionally invoked. The output is stored in the L1 product HDF5 file.
Data Definition & Database	The text report containing the Common Data Descriptor QIs shall be formatted in XML with associated XSD that will be used to validate the XML
Human factors	
Adaptation & Installation	
Validation	Integration test: perform a validation test of the Level0 to Level1 production workflow to verify the generation of the saturated pixel map.

Table 2: Requirement types and examples from VITO PAF

6 Common Algorithms

Within the JRA2 Meeting 04 in May 2010, various approaches for QL generation were proposed as common algorithms. As a result, the following approaches were selected by the JRA2 partners and serve as recommendations for "best practice" within the EUFAR PAFs.

6.1 Approach – aggregated interpolated pixel mask

Within the UZH approach, the interpolated pixel and bad pixel map are based on measurements acquired on an integrating sphere homogenously illuminating the full field of view of the sensor. Ideally, all pixels per band should have identical Digital Numbers (DN). Both the optical system and the individual pixel responses on the sensor chip combine to an individual radiometric response per pixel. Some of these pixels are however insensitive to the incoming radiation and are illustrated as spikes in Fig. 1.

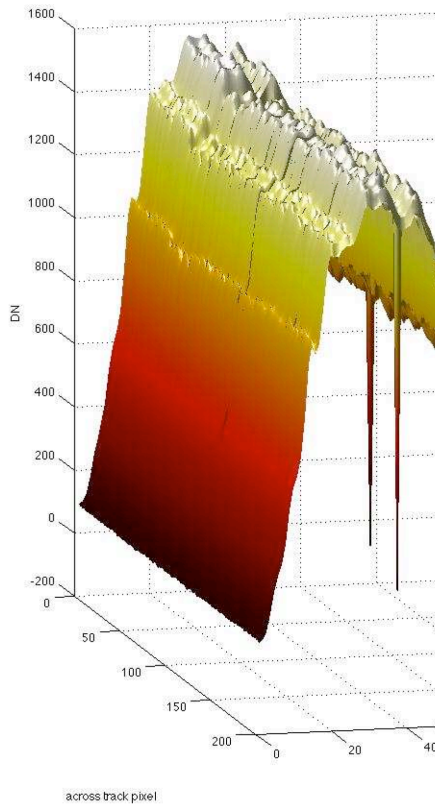


Figure 1: Part of the APEX SWIR detector showing bad pixels as spikes

A bad pixel is considered to have a DN response close to the dark current or a value close to the maximum DN range value irrespective of the actual light input. The aggregated bad pixel map is a Boolean data layer, essentially marking all bad pixels. The bad pixel map is generated after each instrument calibration run in the calibration home base and is actually a side product of the radiometric calibration of the instrument on the integrating sphere.

This bad pixel map is pre-processed before being applied in the data calibration procedure for the benefit of faster data calibration. Bad pixels are sorted into categories the following (see **Error! Reference source not found. & Error! Reference source not found.**):

Correctable bad pixels

Non-correctable bad pixels

Non-correctable bad pixels are pixels that occur in conglomerates, also referred to as 'pixel chunks', on the detector. If the extent of a bad pixel conglomerate is bigger than 3 pixels in across-track direction, the involved pixels are considered as non-correctable as linear interpolation in the spatial dimension leads to unwanted artefacts within the calibrated data. The 'Bad Pixel Chunk Detector' is a process, which filters all pixel conglomerates and classifies them as 'correctable' or 'non-correctable'.

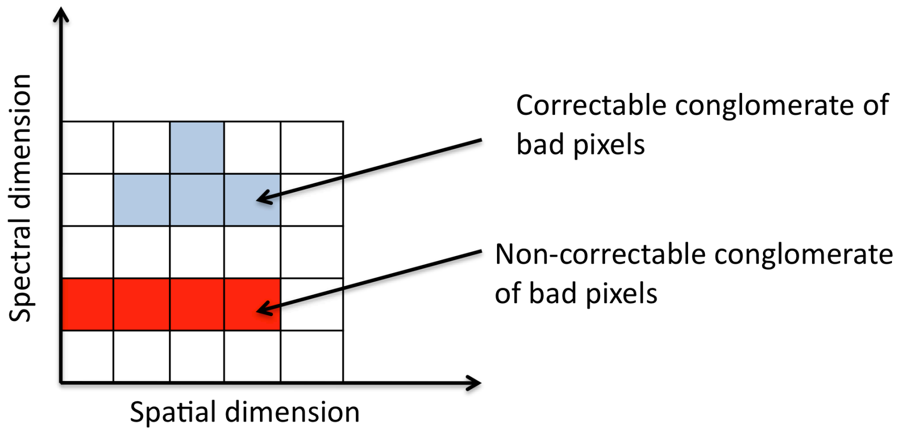


Figure 2: Illustration of bad pixel conglomerates

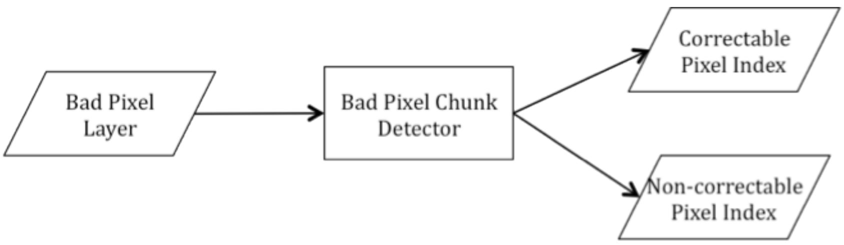


Figure 3: Dataflow of bad pixel correctable/non-correctable layer generation

6.2 Approach – aggregated bad pixel map ("not corrected")

The UZH approach for masking all bad pixels without correction is the same as for flagging interpolated pixels as described in Chapter 6.1.

Within this approach, if the extent of a bad pixel conglomerate is bigger than 3 pixels in across-track direction, the involved pixels are considered as non-correctable and are consequently flagged.

6.3 Approach – saturated pixel / overflow

The process of saturated pixel detection is illustrated in **Error! Reference source not found.**.

In a first step, a frame mask is created, containing the 90% values of the saturation levels defined in a configuration file. These saturation levels are sensor dependant and based on industry specifications or instrument characterisation runs in calibration facilities.
In a second step, the mask is subtracted from every frame; values that assume values above zero are identified as saturated.
Effectively, the saturation detection per frame renders Boolean values and can be summarised as:

This frame information is accumulated and provided to the user in two ways:

a) An accumulated count in along track direction, yielding a final frame that contains the number of occurrences a spatial/spectral pixel was saturated. This helps identifying if critical areas are present on the detector.
b) An accumulated count in spectral direction, yielding a spatial map with the pixel values being equal to the total count of saturated spectral pixels for each spatial position. This immediately helps the user identifying targets causing saturation (**Error! Reference source not found.**).

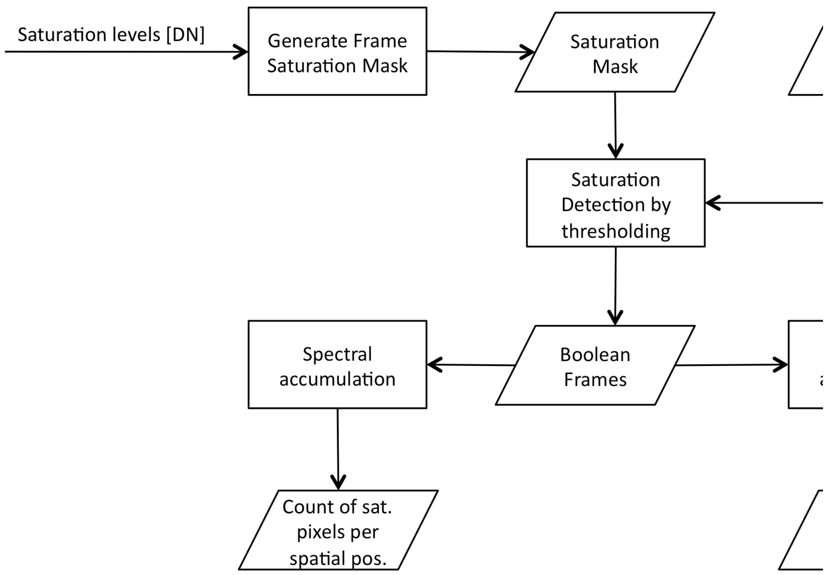


Figure 4: Dataflow of the saturation detection

Figure 5: Example of a spatial saturation quality layer showing the number of saturated bands per spatial position

6.4 Approach – addressing problems with position and attitude information

Based on the experience operating the hyperspectral sensors HyMap, ROSIS and DAIS7915 with various GPS and IMU systems, DLR proposes the following approach. This approach is straightforward and can be easily adapted and extended for sensor-specific errors.

For the position and attitude data, the following sources of errors are taken into consideration:

Completeness

- Check if all GPS/IMU information is present (minimum set: TIME_SIGNATURE, LAT, LON, ALT, PITCH, ROLL, HEADING, DGPS_FLAG)
    - If not: flag dataset for errors
- Check if #lines_image EQ #lines_GPS and #lines_image EQ #lines_IMU
    - If not: flag dataset for errors

Errors in time signature (indicator for missing or erroneous data)

- Calculate average time step between scan lines
- Check if time difference between consecutive lines (forward / backward) is within threshold (based on average time step)
    - If not: flag affected lines for errors

Errors in GPS / IMU data

- Check if position / attitude values are within nominal range
    - If not: flag affected lines for errors
- Check if position / attitude is identical for consecutive lines (indicator for lost data)
    - If so: flag affected lines for errors

Thresholding:
It was agreed that the flag for reduced accuracy is raised if more than one line of GPS- and/or IMU- information is missing.

6.5 Approach – flagging interpolated position and attitude information

For the mentioned DLR sensor–GPS–IMU combinations, usually only small data gaps (< 5 lines) in position and/or attitude data occur, so linear interpolation is a valid baseline. For larger gaps, the usage of advanced methods (i.e., Kalman filtering) should be considered.

Thus for small data gaps, the following procedure is proposed:

In case of missing or erroneous data:
- Identify last n valid entries before and after the missing or corrupt data (n ~ 5)
- Interpolate missing / erroneous information
    - POSITION: linear interpolation as baseline, size of data gap usually not critical
        - Flag affected lines for corrections
    - ATTITUDE: linear interpolation as baseline.
        - If size of data gap / erroneous data GT threshold: flag for errors
        - Else: flag affected lines for corrections

- If invalid data at the beginning or end of file:
    - POSITION: linear extrapolation as baseline, size of data gap usually not critical
        - Flag affected lines for corrections
    - ATTITUDE: use average of last n valid entries as fill value
        - If size of data gap / erroneous data GT threshold: flag for errors
        - Else: flag affected lines for corrections

Thresholding:
It was agreed that the flag for reduced accuracy is raised if more than one line of GPS- and/or IMU- information is interpolated.

6.6 Approach – cloud masking

6.6.1 Cloud masks for L1 products

For the masking of **clouds in L0 or L1 data**, it is suggested by DLR to convert the data to apparent reflectance so that the same band ratios and subsequent threshold values can be used for all scenes. Apparent reflectance ρ^* can be calculated using the following equation:

where L: radiance [mW cm^{-2} sr^{-1} µm^{-1}]
E_s: extraterrestrial solar irradiance in the selected band [mW cm^{-2} µm^{-1}]
θ_s: solar zenith angle (SZA)

For the masking of clouds, usually bands around ~0.5 µm and ~1.6 µm are used. Thus from a software point of view, the following steps are required:

- calculate E_s for selected bands taking into account the spectral response function (e.g., the e0_solar – file generated by the RESLUT function of ATCOR)
- if applicable: define gain and offset values for DN data for selected bands
- if applicable: define scaling values to required radiance units for selected bands
- calculate solar zenith angle (SZA) based on date, time and position
- calculate apparent reflectance for selected bands as
  $\rho^* = (\text{offset} + \text{gain} * \text{DN}) / (\text{e0} * \cos(\text{SZA}))$
  or
  $\rho^* = (\text{scaling\_factor} * L) / (\text{e0} * \cos(\text{SZA}))$

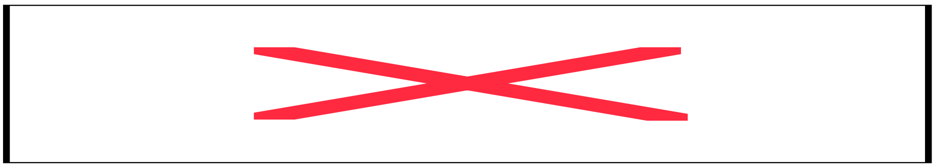
The masking of L0 / L1 data is based on band thresholds:

flag_cloud IF $\rho^*(0.5\ \mu m) > 35\%$ AND $\rho^*(1.6\ \mu m) > 30\%$

To remove single or small clusters of misclassified pixels, the morphological operator “erode” followed by the “dilate” operator is finally applied on the cloud flag map.

6.6.2 Cloud masks for L2 products

For **cloud masking in L2 products**, the ATCOR approach by Richter (2010)[1] is proposed, where cloud pixels must satisfy the conditions:



The ρ* denotes the at-sensor apparent reflectance, T_c is the cloud threshold as defined in the preference file, default $T_c = 0.25$, and NDSI is the normalized difference snow index.

$T_{saturation}$ is defined as 0.9*encoding where encoding $=2^n-1$ and n=bits/pixel. The default factor 0.9 (instead of 1.0) is used as a precaution as some instruments already show a non-linear behavior before entering the nominal saturation limit.

Note that saturated pixels in visible bands are automatically counted as cloud (if NDSI < 0.7) although they might be something else (e.g., specular reflection from a surface).

1 *Richter, R. 2010. Atmospheric/topographic correction for airborne imagery. ATCOR-4 user guide, version 5.1*

6.7 Approach – cloud shadow masking

The proposed cloud shadow masking algorithm of ATCOR contains two algorithms named A1 and A2 here. Algorithm A1 excludes cloud and water pixels and then uses the spectral conditions:

A1 is always executed. Algorithm A2 is an optional supplement if the shadow removal is selected. If A1 and A2 are executed then the two sets of shadow pixels are combined in the cloud shadow mask. Classification ambiguities can occur, because A1 and A2 both rely exclusively on spectral criteria, because water and shadow over land are often difficult to distinguish.

The following brief description of A2 is taken from Richter and Müller (2005)[1] where more details can be found. The sequence of steps is:

1. Atm. correction, i.e. calculation of the surface reflectance.
2. Exclusion of cloud and water areas.
3. The covariance matrix $C(\rho')$ is then calculated where is the surface reflectance vector comprising only the non-water and non-cloud pixels. For each pixel, this vector holds the reflectance values in the 3 selected channels (around 0.85, 1.6, 2.2 µm). The matched filter is a vector tuned to a certain target reflectance spectrum to be detected:

$$V_{mf} = \frac{C^{-1}(\rho'_T - \bar{\rho}')}{(\rho'_T - \bar{\rho}')^T C^{-1}(\rho'_T - \bar{\rho}')}$$

Here, $\bar{\rho}'$ is the scene-average spectrum, without the water/cloud pixels. Selecting =0 for a shadow target yields a special simplified form of the matched filter, where the 'sh' index symbolizes shadow :

$$V_{sh} = -\frac{C^{-1}\,\bar{\rho}'}{\bar{\rho}'^T C^{-1} \bar{\rho}'}$$

4. The shadow matched filter vector is then applied to the non-water/non-cloud part of the scene and yields the still un-normalized values Φ that are a relative measure of the fractional direct illumination, also called unscaled shadow function :

The matched filter calculates a minimum RMS shadow target abundance for the entire (non-water / non-cloud) scene. Therefore, the values of Φ are positive and negative numbers.

5. The arbitrary, image-depending range of Φ has to be rescaled to the physical range from 0 to 1, where 0 indicates no direct illumination (full shadow), and 1 means full direct illumination.

1 Richter, R., and M¨uller, A., "De-shadowing of satellite/airborne imagery", Int. J. Remote Sensing, Vol. 26, 3137-3148 (2005)

6.8 Approach – haze masking

The proposed haze masking algorithm is part of the ATCOR haze detection and removal procedure which is a combination of the improved methods of Richter (1996)[1] and Zhang et al. (2002)[2].

1. Masking of clear and hazy areas with the tasseled cap haze transformation from Crist and Cicone (1984)[3].

where BLUE, RED, x_1= 0.846, and x_2 = -0.464 are the blue band, red band, and weighting coefficients, respectively. The clear area pixels are taken as those pixels where TC is less than the mean value of TC.

2. Calculation of the regression between the blue and red band for clear areas ("clear line" slope angle α). If no blue band exists, but a green spectral band, then the green band is used as a substitute.

3. Haze areas are orthogonal to the "clear line", i.e., a haze optimized transform (HOT) can be defined asZhang et al. (2002)[4]:

4. The default haze mask is defined as those pixels with HOT values higher than the mean minus half its standard deviation:

5. For bands below 800 nm the histograms are calculated for each HOT level j. The haze signal Δ to be subtracted is computed as the DN corresponding to HOT(level j) minus the DN corresponding to the 2% lower histogram threshold of the HOT(haze areas). The de-hazed new digital number is:

Haze removal is performed before the surface reflectance calculation. Cloud pixels are excluded as well as all pixels with *HOT < mean(HOT) + 2 stdev(HOT)*.

6.9 Approach – critical BRDF geometry identification

The aim of this Quality Layer is to raise the user awareness of the BRDF effects on image data. As the precise estimation of BRDF for all surface materials is yet an unsolved problem, and hence no universal approach for the identification of critical BRDF geometries exists, it was agreed to provide the user with all required datasets. For this purpose, the approach by VITO was selected as a common "best practice", and is described in the following.

1 *Richter, R., "Atmospheric correction of satellite data with haze removal including a haze/clear transition region", Computers & Geosciences, Vol. 22, 675-681 (1996)*

2 *Zhang, Y., Guindon, B., and Cihlar, J., "An image transform to characterize and compensate for spatial variations in thin cloud contamination of Landsat images", Remote Sensing of Environment, Vol. 82, 173-187 (2002)*

3 4 *Crist, E. P., and Cicone, R. C., "A physically-based transformation of Thematic Mapper data- the Tasseled Cap", IEEE Trans. Geosci. Remote Sensing, Vol. GE-22, 256-263 (1984)*

4

Error! Reference source not found. presents the output of the VITO orthorectification C++ module for a HYMAP hyperspectral whiskbroom flight-line in Switzerland. The output is a GIS formatted raster with 10 data layers in raw sensor geometry: the X, Y and Z coordinates of every pixel, the solar zenith angle, the local illumination angle, the view zenith, solar azimuth, view azimuth, path length and the sky view factor. For a future release of the orthorectification module, an eleventh layer is foreseen, to mark the occluded areas when using a DSM instead of a DEM.

This geometry grid can be optionally saved in the Level2 HDF5 product. As such, the user has complete information about the local viewing geometry. Since BRDF is also dependent on the target properties and is also wavelength dependent, **it is up to the user to decide which BRDF geometry is critical for his/her application at hand**.

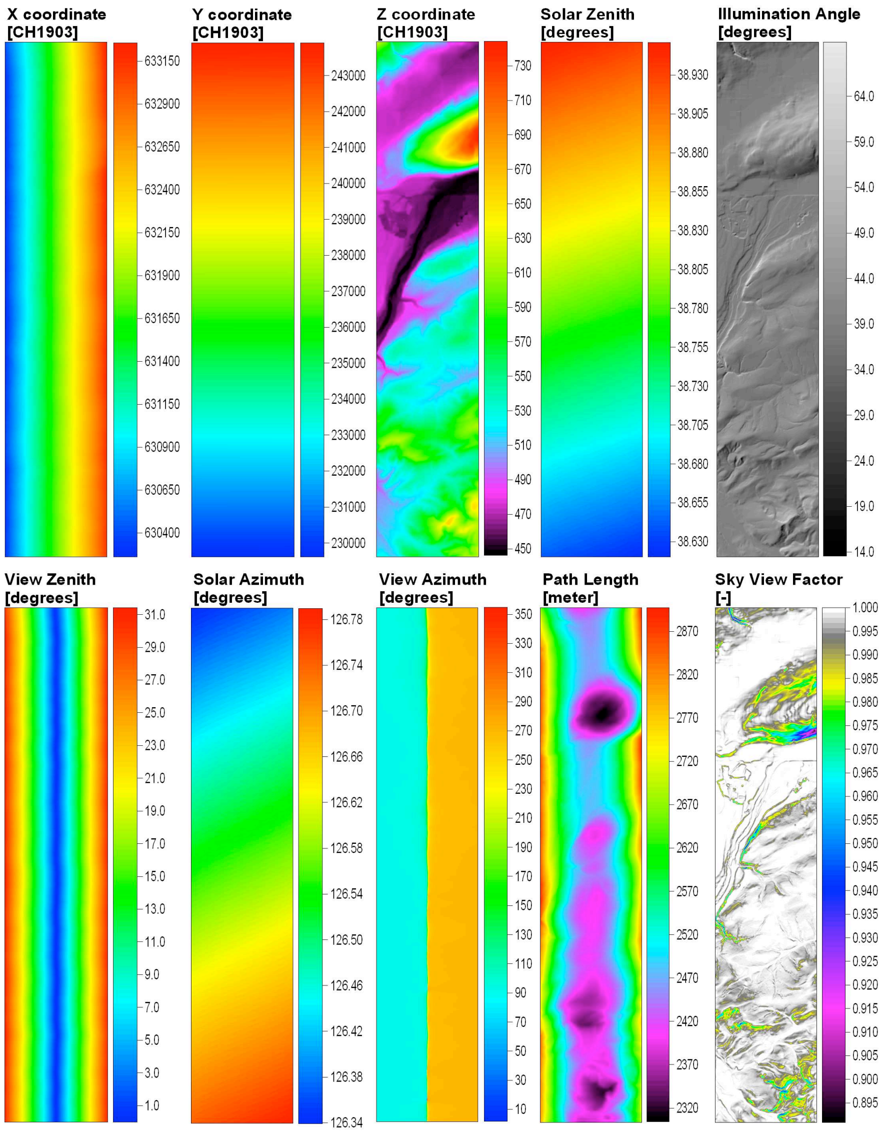


Figure 6. Output of the VITO orthorectification module for a HYMAP hyperspectral whiskbroom flight-line in Switzerland. The coordinate system is CH1903 (Oblique Conformal Cylindrical).

Figure 7 presents the definition for the solar zenith, solar incident angle, solar azimuth, view zenith and view azimuth. In an aircraft and scanner situation, the pointing vector for a pixel may be defined pointing "up" or "down" and there are important issues of whether the scanner scans left to right or right to left. In atmospheric correction routines, the conventions of the scanner and aircraft model frame must be very carefully specified. Any data on angles that came with images being investigated with BRDF models must follow a single convention or be carefully and fully specified. For the following, the consistent convention being used is the "target based" one according Jupp (2000)[1].

In all VITO software modules this target based definition of the angles is always used. Negative view zenith angles will be used in the forward scattering direction (i.e. the direction towards the sun). Negative view zenith angles are only used for plotting. A sign-less view zenith in combination with the relative azimuth is sufficient for the BRDF modeling in MODTRAN or the Kernel BRDF models (Jupp, 2000). In MODTRAN and also in the Kernel BRDF models, the solar azimuth and view azimuth are combined in the relative azimuth. The relative azimuth is an angle that must range between [-180, 180] and can be calculated according (with RA, the relative azimuth, SA the solar azimuth and VA the view azimuth):

$$
\begin{aligned}
&RA = SA - VA \\
&If(RA > +180)\ RA = RA - 360 \\
&If(RA < -180)\ RA = RA + 360
\end{aligned}
$$

[1] Jupp, D.L.B. 2000. A compendium of kernel & other (semi-)empirical BRDF Models. CSIRO Technical Report. 18p.

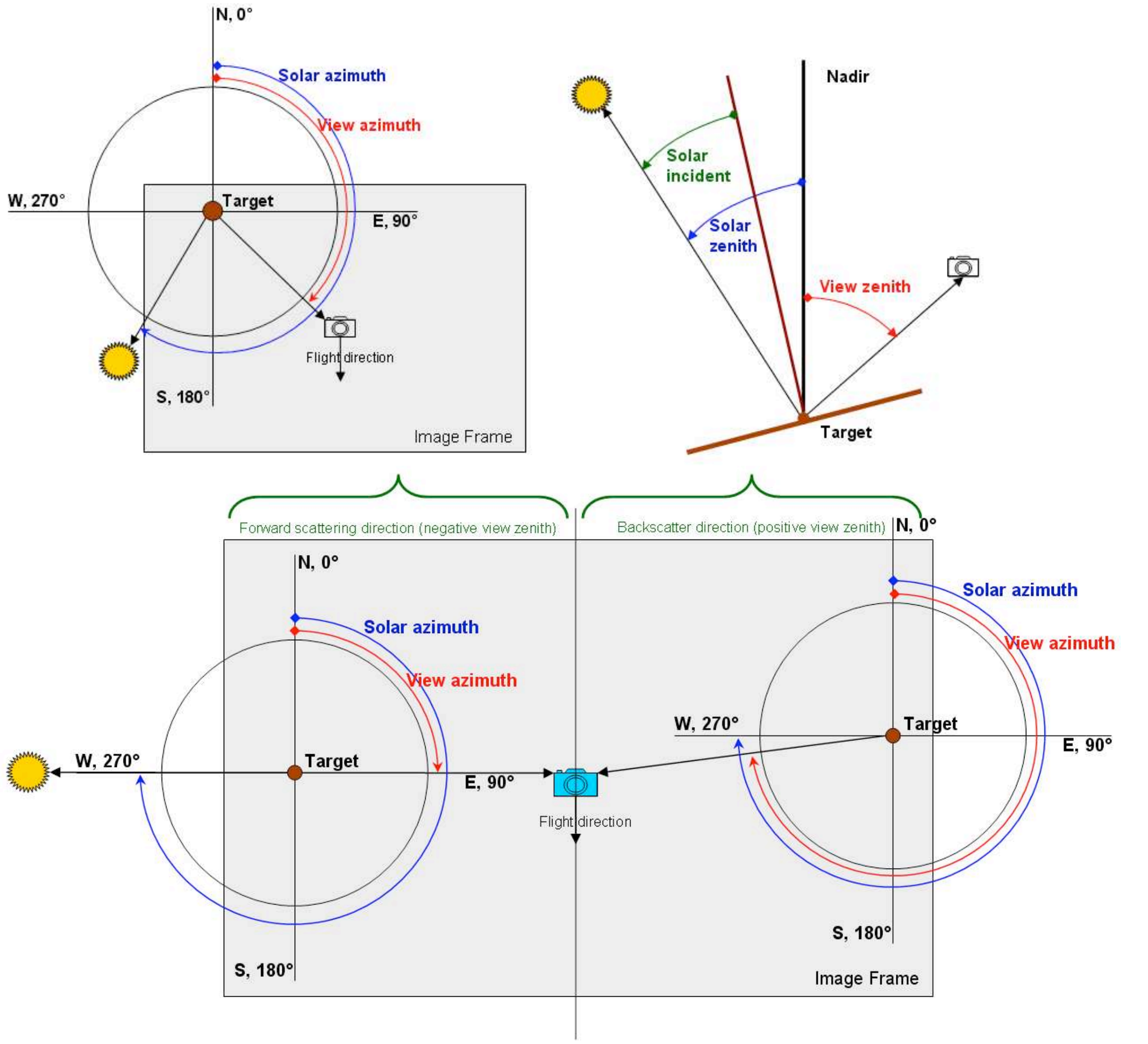


Figure 7. Definition of the solar zenith [0, 90], solar incident angle [0, 90], solar azimuth [0, 360], view zenith [0, 90] and view azimuth [0, 360].The angle definitions are target based. In the lower figure, the relative azimuth of the target in the backscatter direction is about 10 degrees, the relative azimuth of the target in the forward scattering direction is 180 degrees.

For the determination of the local illumination angle, one needs the local aspect and slope of the imaged surface. For the determination of slope and aspect, the Zevenbergen and Thorn (1987[1]) algorithm is used in the VITO PAF. The illumination angle, β, can then be written as:

$$\cos(\beta) = \cos(SZ)\cos(slope) + \sin(SZ)\sin(slope)\cos(SA - aspect)$$

with SZ the solar zenith and SA the solar azimuth. All these pixel-dependent angles are calculated and saved during the orthorectification process (see **Error! Reference source not found.**).

[1] Zevenbergen, L.W. and C.R. Thorne. 1987. Quantitative analysis of land surface topography. Earth Surface Processes and Landforms, 12:47-56.

7 Implementation of Quality Layers at DLR

In this chapter, the implementation of the EUFAR JRA2 Quality Layers and Data Descriptors is described, as well as recent developments related to Data Quality. Special focus is set on the processing of HyMap data, as this sensor is most frequently used.

7.1 Recent developments at DLR PAF

In addition to the extension of DLRs PAF for the EUFAR Quality Indicators, the following developments contribute to the aims of JRA2. Thus Chapter 7.1 can be seen as an update to the PAF description in EUFAR JRA2 DJ2.1.1 and DJ2.1.2.

7.1.1 Estimation of thresholds for nominal position and attitude information

As the DLR PAF also includes additional tests for plausibility and rapid changes in the position and attitude data, thresholds for the nominal data ranges and nominal variability are required. For this purpose 3 years of HyMap data were analysed in order to derive the nominal value range and the related variability.

	Nominal data range	Nominal variability within one flightline	Nominal variability between two scanlines
Lat / Lon	Lat -90 … +90° Lon -180 … +180°	–	Delta < $2*10^{-4}$ °
Altitude agl	1800 – 5300 m	Delta < 25 m Stdev < 5 m	Delta < 1 m
Pitch	abs (0 – 2.5°)	Stdev < 0.5°	Delta < 0.1°
Roll	abs (0 – 3.0°)	Stdev < 0.6°	Delta < 0.1°
Heading	0 – 360°	Stdev < 2.0°	Delta < 0.2°
Speed	50 – 90 m/s	Stdev < 1.6 m/s	Delta < 0.1 m/s

Table 3: Nominal value range and related variability of position and attitude information

Note that these values are depending on the GPS/IMU (esp. on the data rate), the platform (stabilized or not) and the specific flight setup (e.g., above mountainous terrain), and are therefore considered as empirical *indicators*. In addition, the related uncertainties (as described in DJ212) should be taken in consideration.

7.1.2 Automated data checks related to radiometric calibration

Regarding *data* properties related to radiometric calibration and the stability of calibration, there is the necessity for an operational and automated check since the correctness of radiometry is most essential. Therefore the following new approach is currently in development and will soon be implemented in the processing chain.

Approach:

1. Calculation of average spectral radiance and standard deviation separately for every image column of the whole image

   Where

   $\bar{L}(x,b)$: mean radiance value for image column x in band b over all scan lines y

   $\sigma L(x,b)$: standard deviation of radiance values for image column x in band b over all scan lines y

   n: total number of scan lines of the image.

2. Calculation of band-to-band correlation matrix (using Pearson correlation coefficient) separately for every image column of the whole image

   Alternatively the band-to-band variance-covariance matrix can be used.

3. Analysis of band-to-band correlation / co-variance

   For a first assessment, the band-to-band correlation matrix can be used. Due to the continuous sampling of the wavelength range with narrow bands, the correlation between neighbouring bands is generally high for hyperspectral data sets in comparison to multispectral systems.

   For a well-calibrated system without band defects, the correlation between neighbouring bands (i.e., data values close to diagonal) is high. Note that there is a generally reduced correlation of bands with atmospheric absorption (horizontal and vertical lines).

   If single bands of a sensor are de-calibrated, or if these bands contain data defects, the band-to-band correlation is reduced. This can be seen in Figure 10 as thin horizontal and vertical lines which occur especially in the SWIR (high band numbers).

   The **visual inspection** of these plots is a quick method in order to detect critical bands or wavelength ranges for further investigation.

   Also the **automated analysis** of the band-to-band correlation matrix is foreseen for suitable scenes (criteria listed in next paragraph 4)). Based on archived data the typical band-to-band correlation is estimated for each band, as well as the standard deviation. Thus the nominal range of correlation coefficients for each band is known and can be used as threshold. For stable bands (i.e., bands with a small typical range), altered response of a detector element will result in reduced correlation values; as soon as values are below the thresholds, an alert will be triggered, and interactive analysis will be carried out. In case of failure of complete adjacent bands, the correlation will reach values of 1 which will also trigger alerts.

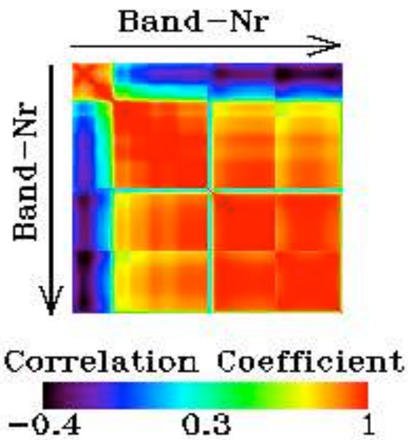


Figure 8: Example for band-to-band correlation matrix with no band defects (HyMap sensor data)

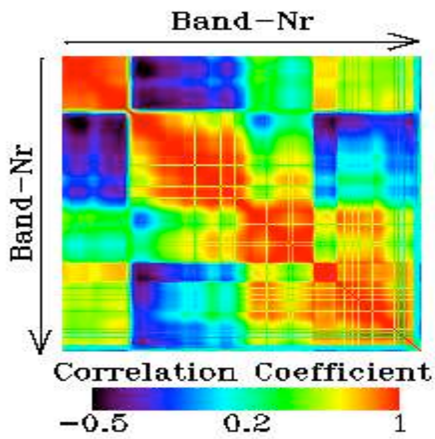


Figure 10: Example for band-to-band correlation matrix with band defects (data from AISA Dual sensor with known stability problems)

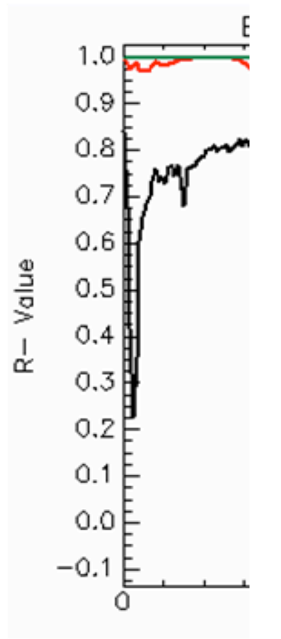


Figure 10: Example for the correlation factors between two subsequent bands (estimates based synthetic example). Black curve: uncalibrated raw DN; red: calibrated radiances with slight decalibration; green: accurately calibrated radiances

4. Test if scene is useful for additional automated analysis, i.e. assumption above on scene statistics and homogeneity is valid.
   Criteria: column average spectra and standard deviations are similar within (TBD) values of the combined spectral similarity measure by DU et al., 2004. This advanced approach was developed for hyperspectral data, and was found to be highly suitable for measuring the similarity between two spectra. The measure is based on a combination of the well-known geometric vector measure Spectral Angle Mapper (SAM) with the probabilistic information measure Spectral Information Divergence (SID).
   If the columns are highly dissimilar, then the scene is likely heterogeneous, which renders the subsequent analysis meaningless and is skipped. Thus the **automated test** triggers the following QC processing.

5. Test for artefacts

Artefacts related to single instable detectors can be **automatically** checked when the scene homogeneity criterion is fulfilled. In this case the correlation of neighbouring bands (for pushbroom sensors also neighbouring bands within one column) should be within nominal range. Note that bands at wavelengths where strong atmospheric absorption occurs are excluded.
Note further that for pushbroom instruments the check fails if the response of an entire detector line is altered, i.e if all pixels of a channel are affected in the same way.

6. Analysis for striping (pushbroom sensors only):
   If the radiometric response of a detector element is slightly changed (i.e., incorrect or instable gain and offset values) in relation to the spatially adjacent detectors, the corresponding column in the affected image band appears brighter or darker than the adjacent columns. Other causes of striping include dirt on a detector element, or shift of the entrance slit in-flight relative to the in-lab characterization resulting in a not fitting response matrix. See point C) below for examples.
   For all the mentioned causes, from a data processing point of view, a single striping column thus has a higher or lower average radiance when compared to adjacent columns, and also a low correlation with adjacent columns.
   In order to detect such detector elements, thresholds based on absolute difference of (TBD) in radiance units can be used:

   Note that the analysis must consider also additional influencing factors. I.e., a cross-track brightness gradient can also be caused by spectral smile, strong BRDF behaviour of surfaces materials.

   In order to analyze the cause of striping, the same analysis shall be applied to "corrected" DN values:

   whereby the DN values shall be corrected for system effects (i.e., nonlinearity, dark values, stray light and dual gain), but no radiometric calibration coefficients shall be applied. This way one can separate effects related to the detectors (e.g., dirt) which are already visible in the DN values from effects related to the calibration (i.e., gain values) which show up only in the radiance data.

   Automated tests can be carried out based on these criteria if the scene homogeneity criteria described above is met.

7. Analysis for banding:
   Affected band over all columns has higher or lower radiance and low correlation with adjacent bands

   Note that the analysis must consider also additional influencing factors like bands within atmospheric absorptions, or where dominant materials have narrow absorption features. **Automated tests** can be carried out for these suitable bands.

7.1.3 Including data quality estimates in overall survey workflow

Within the ISO9001:2008 certified user service “OpAiRS”, several procedures are included to check data quality and meet customer’s requirements.

First, a fixed procedure “from survey request to data delivery” within the workflow ensures that both, users and staff double-check important steps and products. For example the flight planning of the strips has to be verified by the user and has to run through a technical check within the flight service. Also, in case of a sensor malfunction and problems during or after a survey a non-conformity handling followed by a report ensures that the incident will be analysed, corrected and avoided in future surveys. Based on over 12 years experience in processing and operating hyperspectral sensors, procedures were developed in order to accomplish all steps e.g. calibration, estimation of boresight misalignments and sensor operations on a high standard.

In addition, the Quality Layers and Data Quality Reports will be provided to the user with every dataset. Therefore data processing and its quality are comprehensible and well documented. Customers can check every data set and have insight in the individual processing parameters after the data delivery.

In order to improve the quality of the whole survey, customer feedback is included. Such feedback includes different aspects such as data quality, communication, management and contractual issues. These feedback forms are essential to assure a high quality service and give indicators on necessary improvements.

For the overall survey workflow of OpAiRS see **Error! Reference source not found.**.

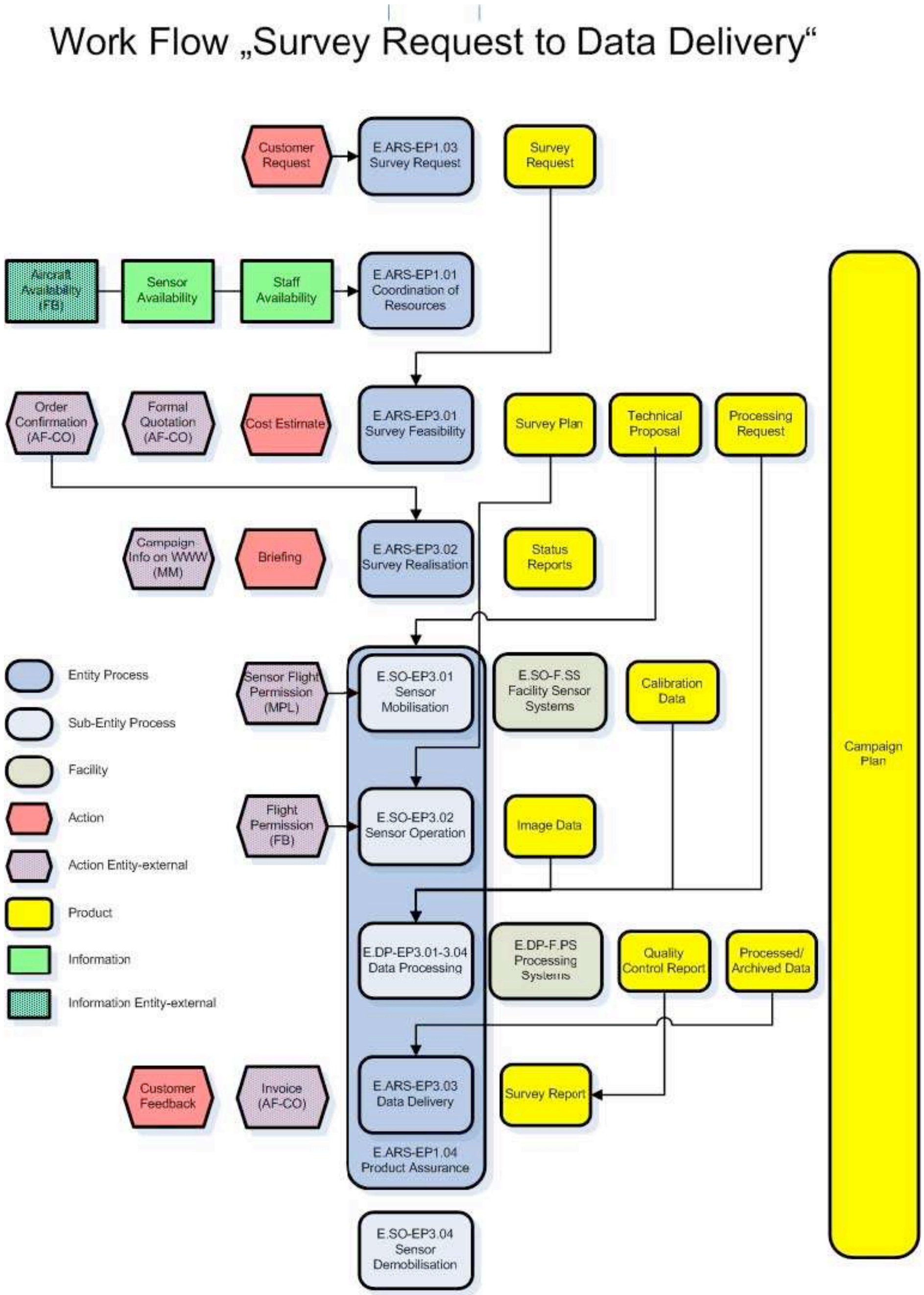


Figure 11: Overall survey workflow within DLRs OpAiRS service.

7.2 Description of algorithms

7.2.1 Aggregated bad pixel mask ("not corrected")

As for HyMap no dead pixels exist on the line detectors, consequently only a dynamic (i.e., image-based) approach with no input from laboratory characterization is used.

In this approach, a pixel is masked as "bad" if it has a negative radiance or reflectance value. In addition, a pixel is also considered as "bad" if it has a radiance or reflectance value of zero, and is not classified as "water". The rationale for this classification step is that water pixels often have reflectance values close to zero in the SWIR region. As the sensor calibration is usually less than perfect, this frequently results in pixel values of zero in these bands even in case of a functioning sensor. For L1 data, the classification is based on threshold on apparent reflectance data (see Chapter 6.6). For L2 data, the water mask generated by ATCOR is used (Richter 2010[1]).

7.2.2 Aggregated interpolated pixel mask ("corrected")

As DLRs mainly operates the HyMap whiskbroom sensor, currently no problems with dead or instable pixels are known. Therefore currently no interpolation of bad pixels is implemented. But as the PAF will be extended for other sensors, this Quality Layer will be used in the future.

7.2.3 Saturated pixel / overflow

For HyMap, a simple thresholding in L0 data is used as saturation is reliably detected in raw DN data. The applied threshold for all 4 spectrometers is DN > 3800. Note that this mask is further updated after system correction (L1) where the encoding threshold of DN = 32766 is used, and also after atmospheric correction, where a threshold of, $\rho > 90\%$ is applied. Also note that no overflow / cross-talk is known for HyMap, thus no algorithm was developed for this task.

7.2.4 Problems with position and attitude information

The DLR approach is described in Chapter 6.4

7.2.5 Interpolated position and attitude information

The DLR approach is described in Chapter 6.5

7.2.6 Cloud mask

The DLR approach is described in Chapter 6.6

7.2.7 Cloud shadow mask

The DLR approach is described in Chapter 6.7

1 *Richter, R. 2010. Atmospheric/topographic correction for airborne imagery. ATCOR-4 user guide, version 5.1*

7.2.8 Haze mask

The DLR approach is described in Chapter 6.8

7.2.9 Critical local viewing and illumination geometry

In accordance to the approach described in Chapter 6.9, the following layers will be provided for each L2 product:

- View zenith angle (data layer, angle in degrees * 100)
- View azimuth angle (data layer, angle in degrees from north towards east * 10)
- If requested: local illumination (data layer, based on cos of local solar zenith angle)
- Solar zenith (data descriptor)
- Solar azimuth (data descriptor)
- If requested: sky view factor (data layer)

These data layers are generated as standard outputs of ORTHO and ATCOR (see Richter 2010[1] for full description).

7.2.10 Additional PAF-Specific QIs

- Rapid changes in position and attitude
  As PAF-specific parameters, the difference in position and/or attitude between two scan lines is included. The approach is as follows, with the threshold given in Chapter 7.1.1:

  Rapid changes in attitude / position
  - Check if difference in attitude / position between consecutive lines is LT threshold
    - If not: flag affected lines for reduced quality

- Problems with GPS and/or DGPS signal
  In addition to the common DataDescriptor, a PAF-specific QI flag is provided indicating in which lines problems with the GPS (i.e., GPS signal from less than 4 satellites) or DGPS (i.e., no signal available) did occur.

- Land-Water-Shadow mask
  As mentioned in Chapter 7.2.1, water pixels are treated differently during the masking of bad pixels. To provide the end user with all required information for traceable masking, the land-water-shadow masks are also distributed.
  For L1 data, thresholding based on apparent reflection is applied.
  For L2 data, the haze – cloud – water mask (HCW) generated in ATCOR is provided.

- Overall Quality
  The measure used for addressing the overall data quality for a given pixel is based on the combination of the following QIs:

1 Richter, R. 2010. Atmospheric/topographic correction for airborne imagery. ATCOR-4 user guide, version 5.1

QI	Valid for	Reduced Quality if	Low Quality if
Saturation	Pixel	> 1 band	> 10 bands
Zero data values	Pixel	> 1 band	> 10 bands
Haze / Cloud	Pixel	Haze or cloud	
Problems in position / attitude	Scanline	Interpolated	No interpolation possible
Rapid changes in position / attitude	Scanline	Exceeding nominal data range	Exceeding plausible data range
Number of GPS satellites	Scanline	< 4 satellites	
DGPS available	Scanline	No DGPS	

Table 4: QIs as a measure for the overall data quality for a given pixel

A pixel is always flagged as “Low Quality” if one or more of the criteria described above for “low” occur. For Reduced Quality, one or more of the criteria described above for “reduced” are met, but no criteria for “low”. Nominal pixels should not fulfil any criteria of “low” or “reduced”.

7.3 Integration in processing chain

In the following, the implementation of the DataQC routines within the automated DIMS-AIROS processor of DLR is depicted. For a closer description of the PAF, please refer to EUFAR DJ211 and DJ212.

In Fig. 12, the overall processing workflow including the DataQC is depicted. Within this modular processing chain, SW modules dedicated to build the QIs are called by processors therefore allowing an easy extension and update according to the developments made in EUFAR JRA2.
The detailed sequence for L0 / L1 and L2 DataQC can be found in Fig. 13 and Fig. 14. Note that the L1 Data Descriptors and L1 Quality Layers are input for the L2 DataQC, as some of the QIs are updated.

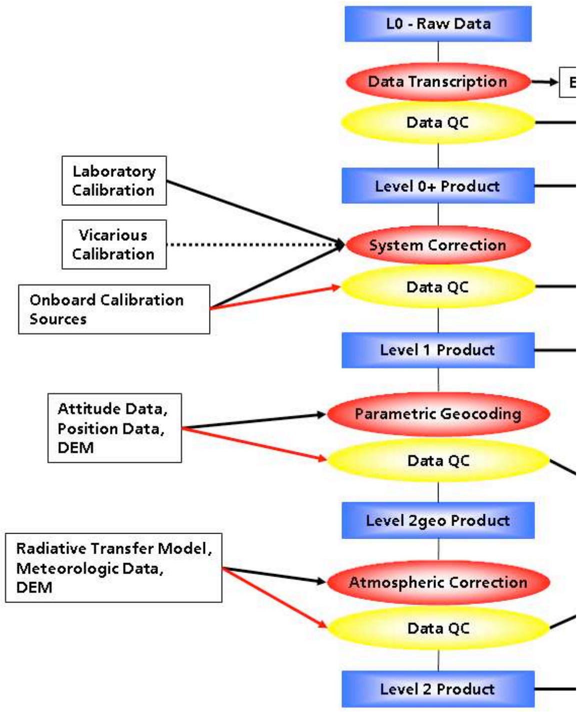


Figure 12: General flowchart of processing at DLR’s PAF

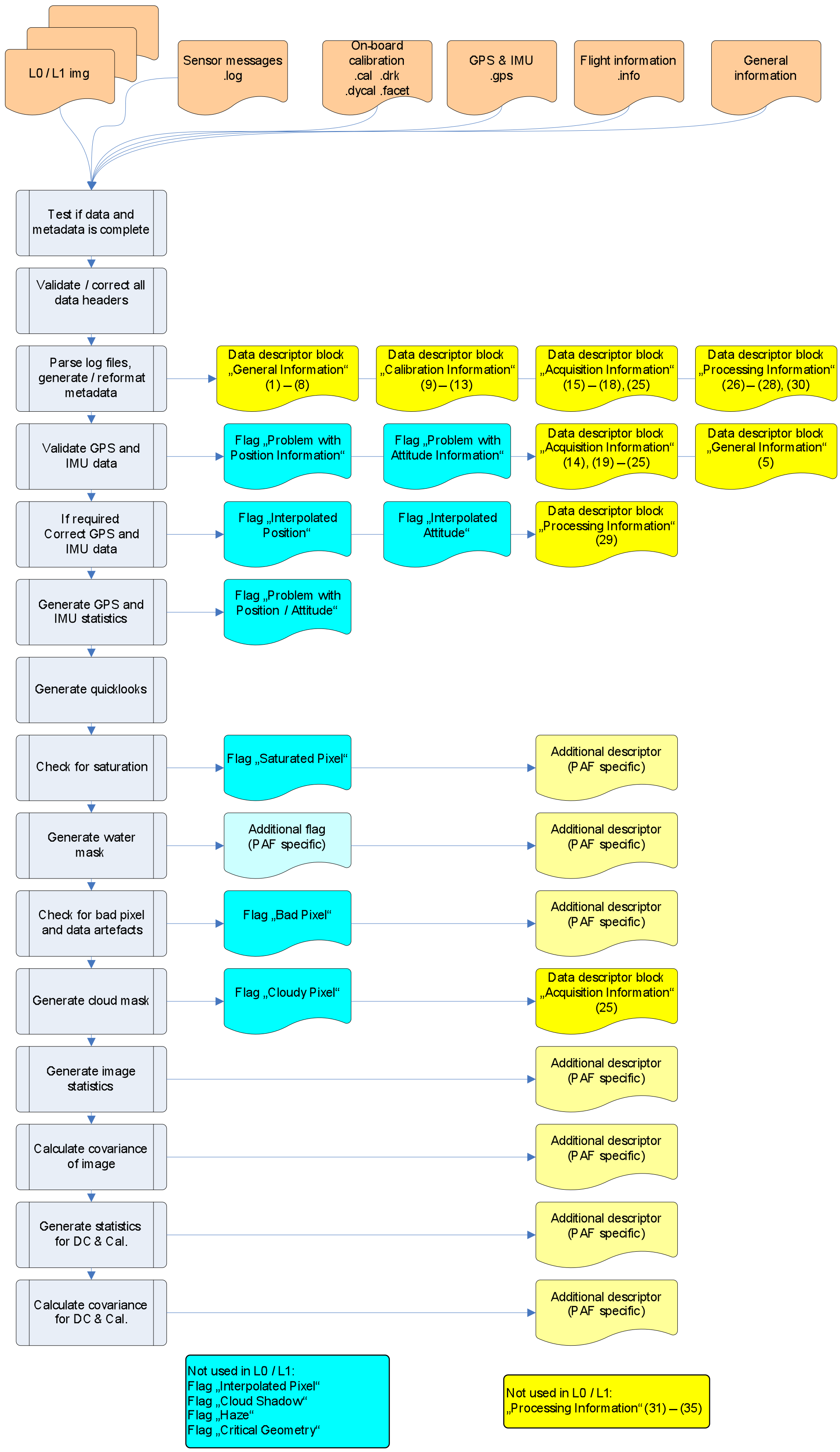

L0 / L1 img
Sensor messages .log
On-board calibration .cal .drk .dycal .facet
GPS & IMU .gps
Flight information .info
General information
Test if data and metadata is complete
Validate / correct all data headers
Parse log files, generate / reformat metadata
Data descriptor block „General Information“ (1) – (8)
Data descriptor block „Calibration Information“ (9) – (13)
Data descriptor block „Acquisition Information“ (15) – (18), (25)
Data descriptor block „Processing Information“ (26) – (28), (30)
Validate GPS and IMU data
Flag „Problem with Position Information“
Flag „Problem with Attitude Information“
Data descriptor block „Acquisition Information“ (14), (19) – (25)
Data descriptor block „General Information“ (5)
If required Correct GPS and IMU data
Flag „Interpolated Position“
Flag „Interpolated Attitude“
Data descriptor block „Processing Information“ (29)
Generate GPS and IMU statistics
Flag „Problem with Position / Attitude“
Generate quicklooks
Check for saturation
Flag „Saturated Pixel“
Additional descriptor (PAF specific)
Generate water mask
Additional flag (PAF specific)
Additional descriptor (PAF specific)
Check for bad pixel and data artefacts
Flag „Bad Pixel“
Additional descriptor (PAF specific)
Generate cloud mask
Flag „Cloudy Pixel“
Data descriptor block „Acquisition Information“ (25)
Generate image statistics
Additional descriptor (PAF specific)
Calculate covariance of image
Additional descriptor (PAF specific)
Generate statistics for DC & Cal.
Additional descriptor (PAF specific)
Calculate covariance for DC & Cal.
Additional descriptor (PAF specific)
Not used in L0 / L1:
Flag „Interpolated Pixel“
Flag „Cloud Shadow“
Flag „Haze“
Flag „Critical Geometry“
Not used in L0 / L1:
„Processing Information“ (31) – (35)

Figure 13: Workflow for the derivation of Quality Layers (blue) and Data Descriptors (yellow) based on L0 / L1 data. The Data Descriptor numbers refer to the lists in Chapter 4.3.

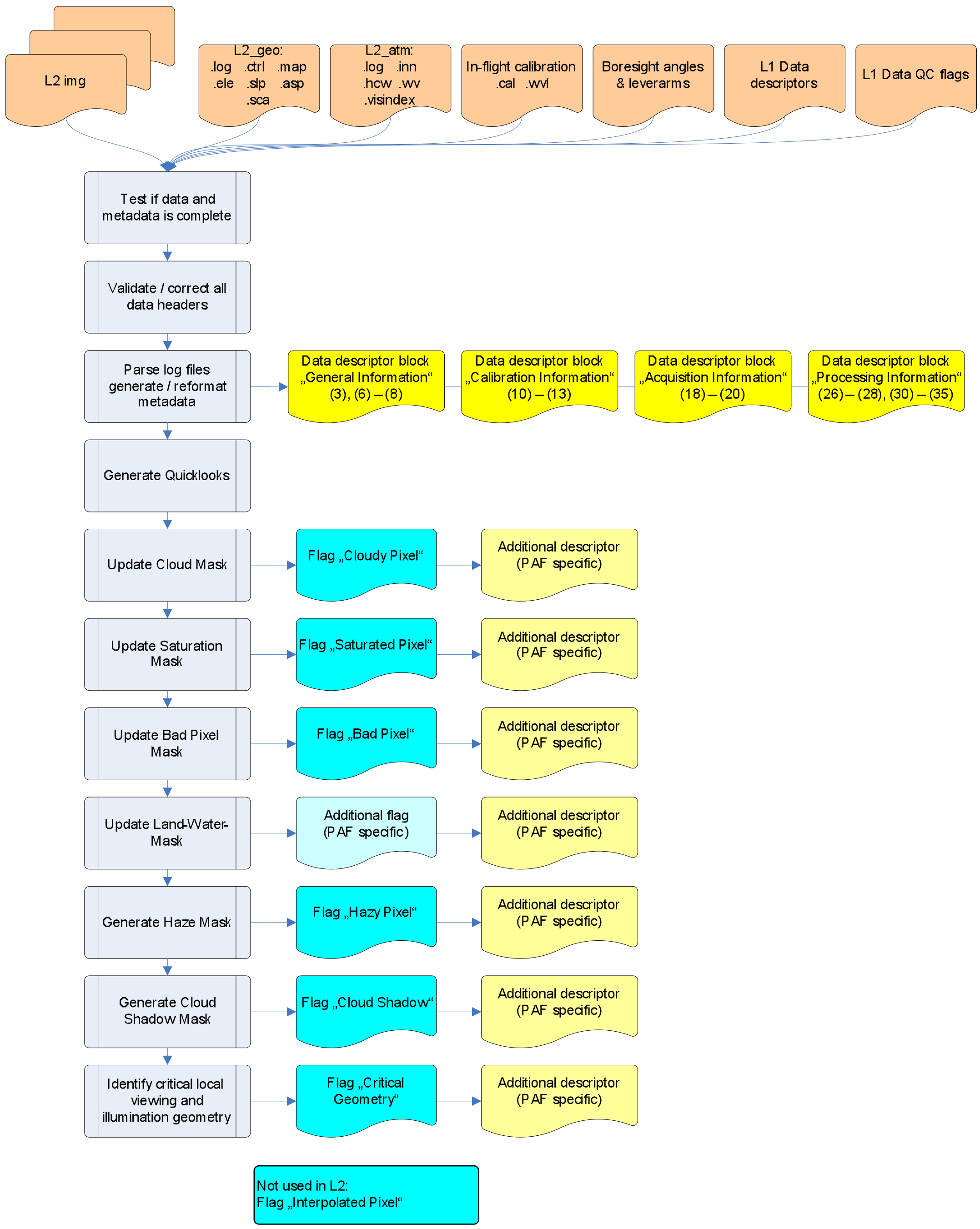


Figure 14: Workflow for the derivation of Quality Layers (blue) and Data Descriptors (yellow) based on L2 data. The Data Descriptor numbers refer to the lists in Chapter 4.3.

7.4 Examples for Quality Layers and Data Descriptors

In the following, examples for the Quality Layers are presented.
These Quality Layers are included in an ENVI file, where every band represents a certain Quality Indicator. Currently, the implementation of the Quality Layers in an EUFAR-agreed HDF5 format is in progress.

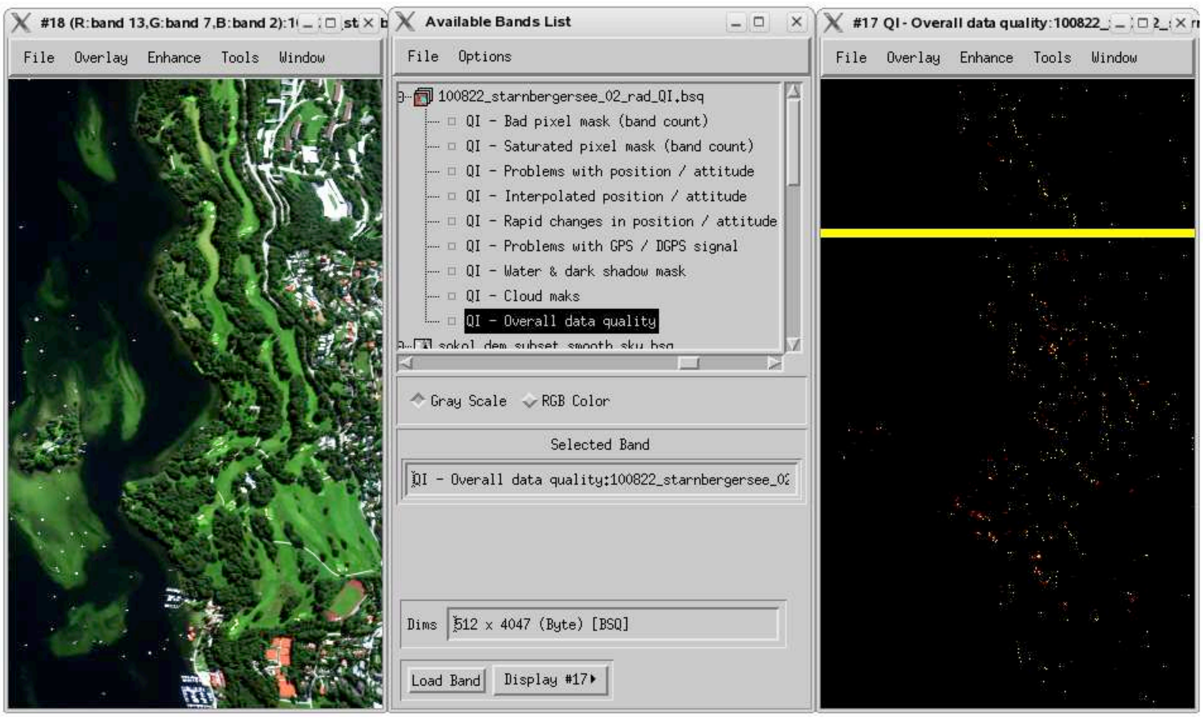


Figure 15: Example for QLs as implemented in the DLR PAF.

Figure 16: True color RGB of L1 product

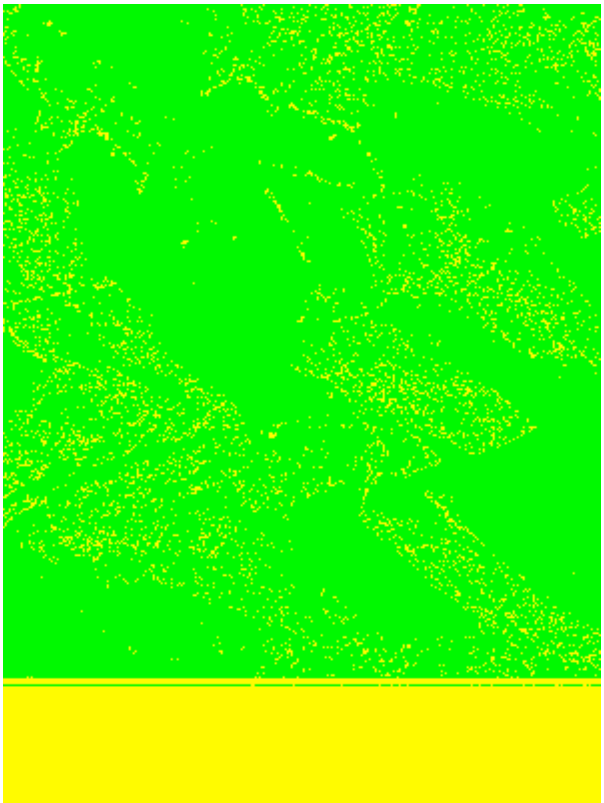


Figure 17: QL - Overall data quality (PAF-specific)

Figure 18: Water & dark shadow mask (PAF-specific)

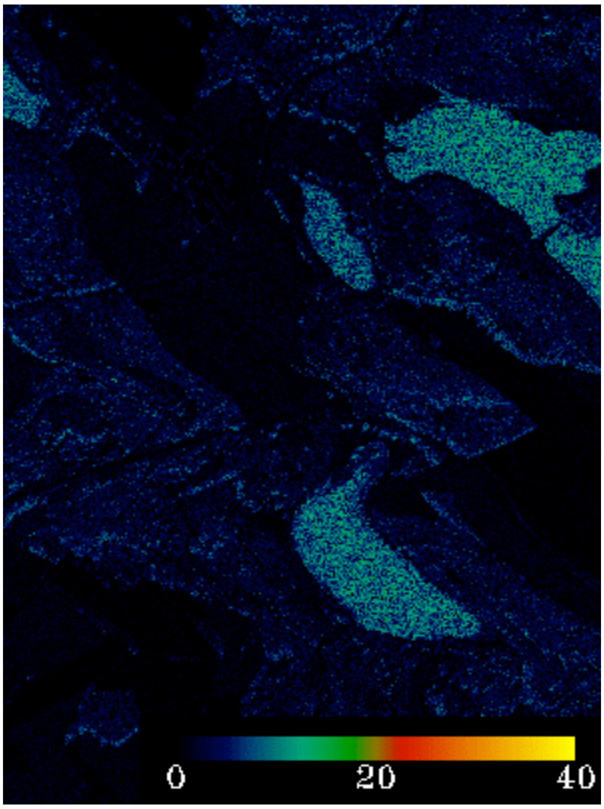


Figure 19: QL - Aggregated bad pixel mask (zero DN count, no water mask considered)

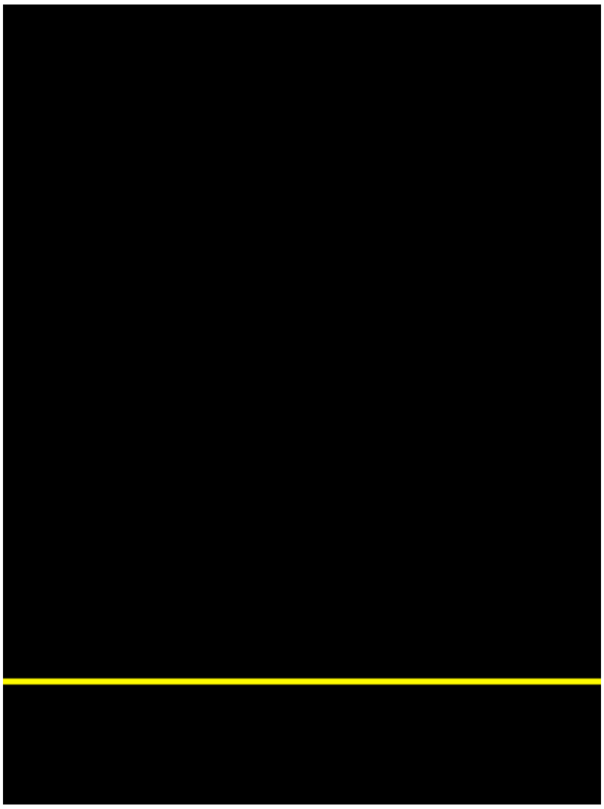


Figure 20: QL – Interpolated position / attitude. Note the flag for "interpolated data" corresponding to scan lines 338 - 340.

Figure 21: QL – Problems with GPS / DGPS signal (PAF-specific)

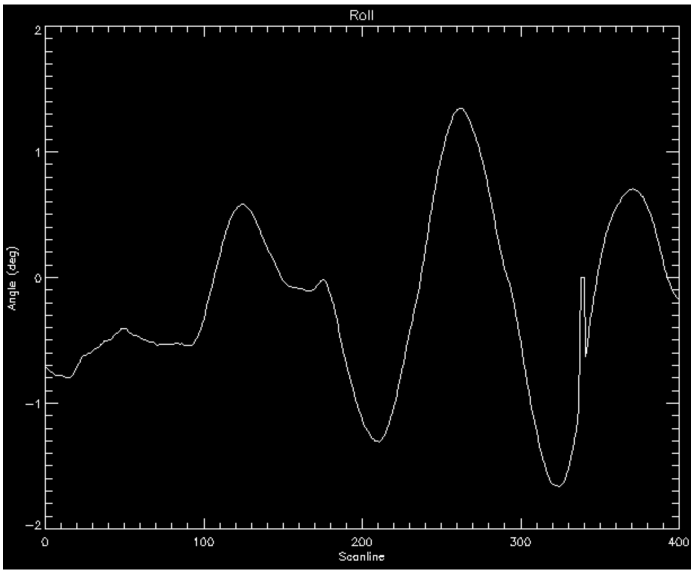


Figure 22: Corresponding plot of the roll angle for L0 data (not corrected)

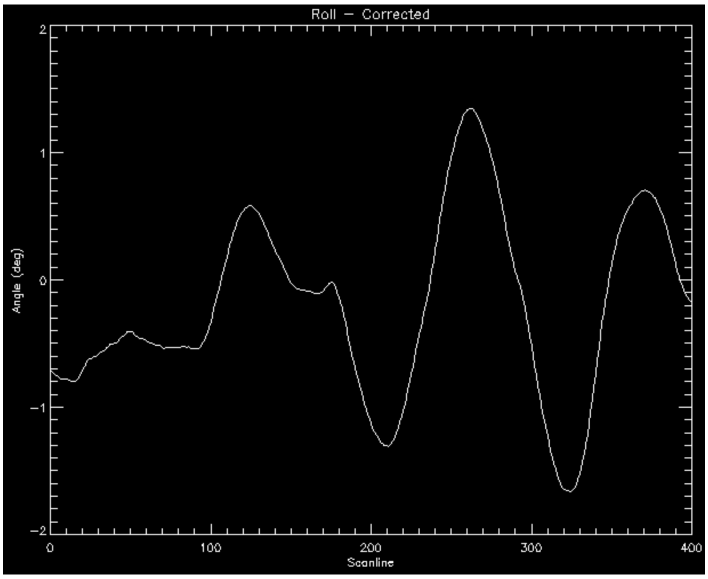


Figure 23: Corresponding plot of the roll angle for L1 data (interpolated)

Figure 24: Atm.corrected image, RGB

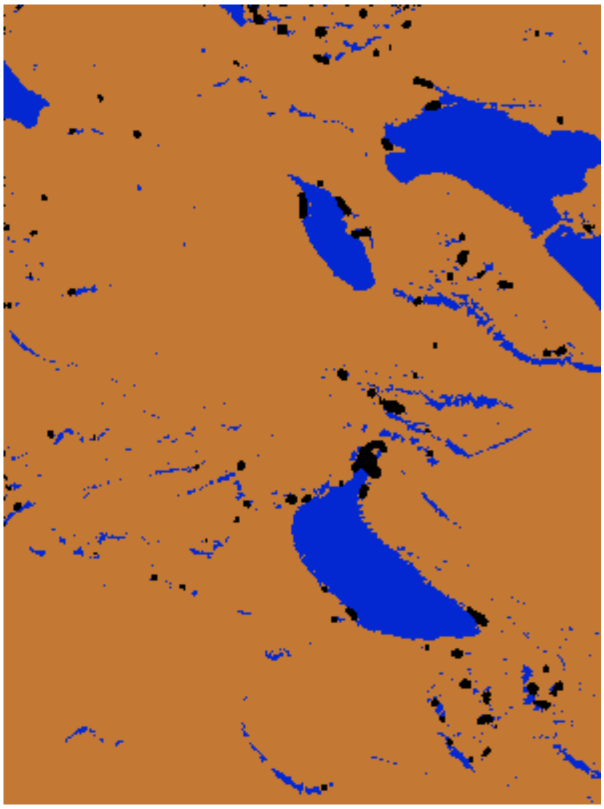


Figure 25: HCW (Haze Cloud Water) Mask

Figure 26: Water vapor column (cm * 1000)

Figure 27: Orthorectified image (RGB)

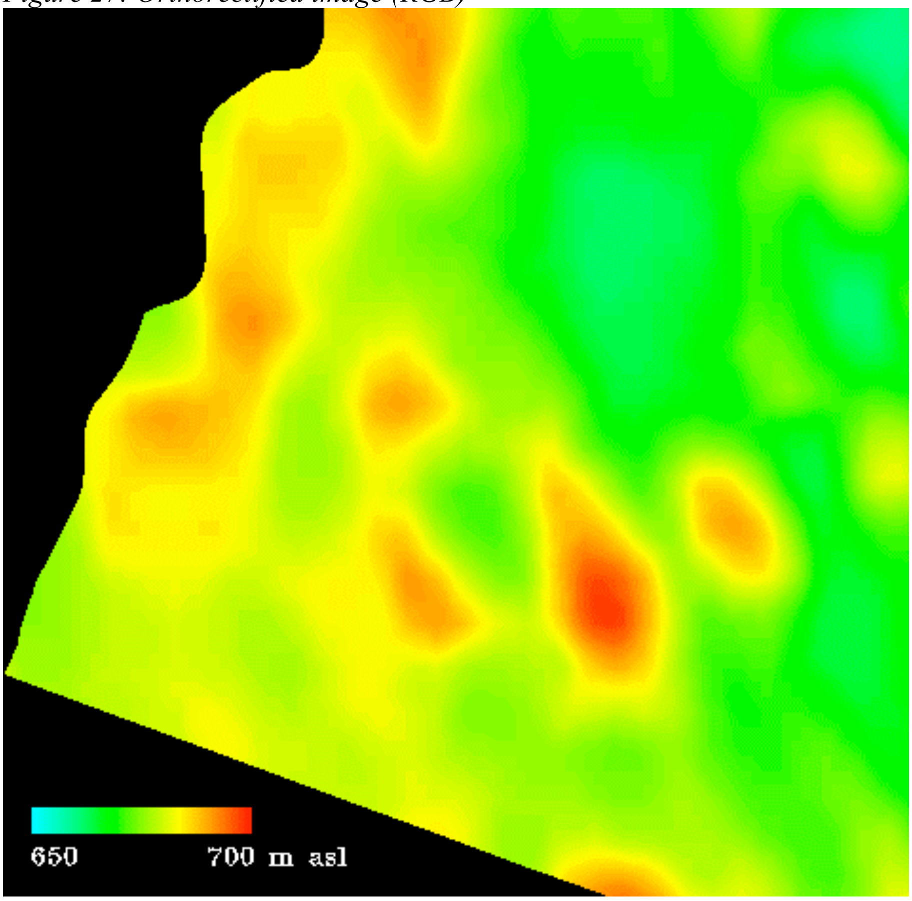


Figure 28: DEM

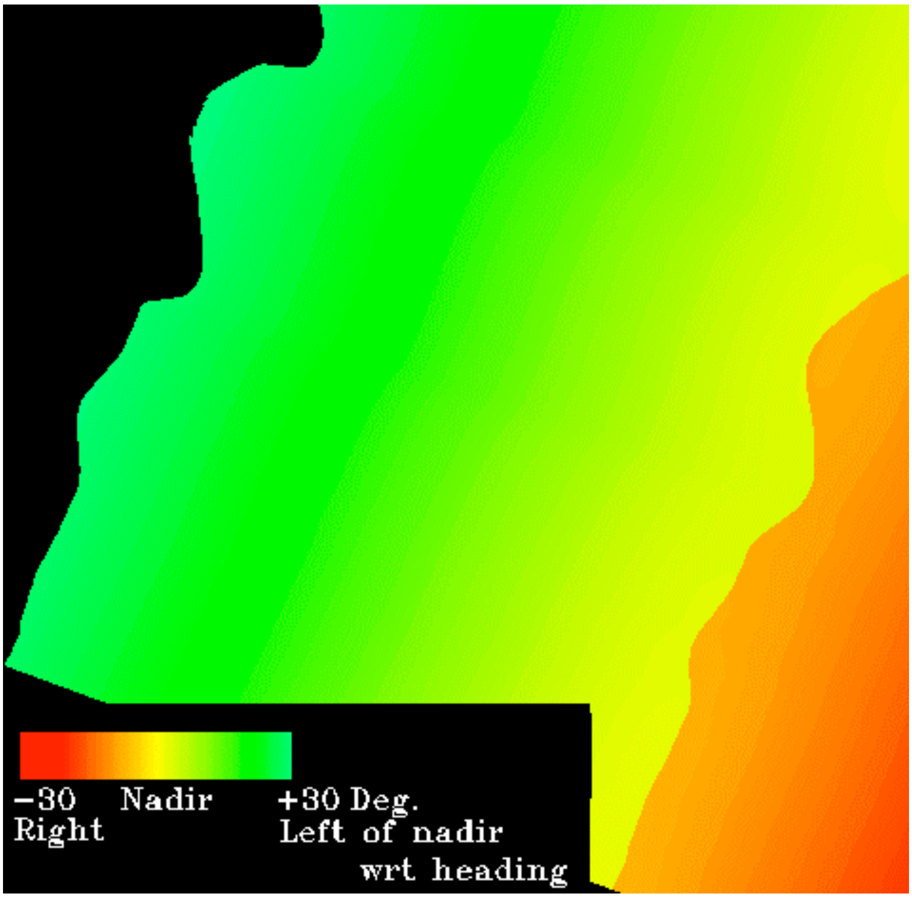


Figure 29: Scan view angle (additional scan azimuth angle not depicted)

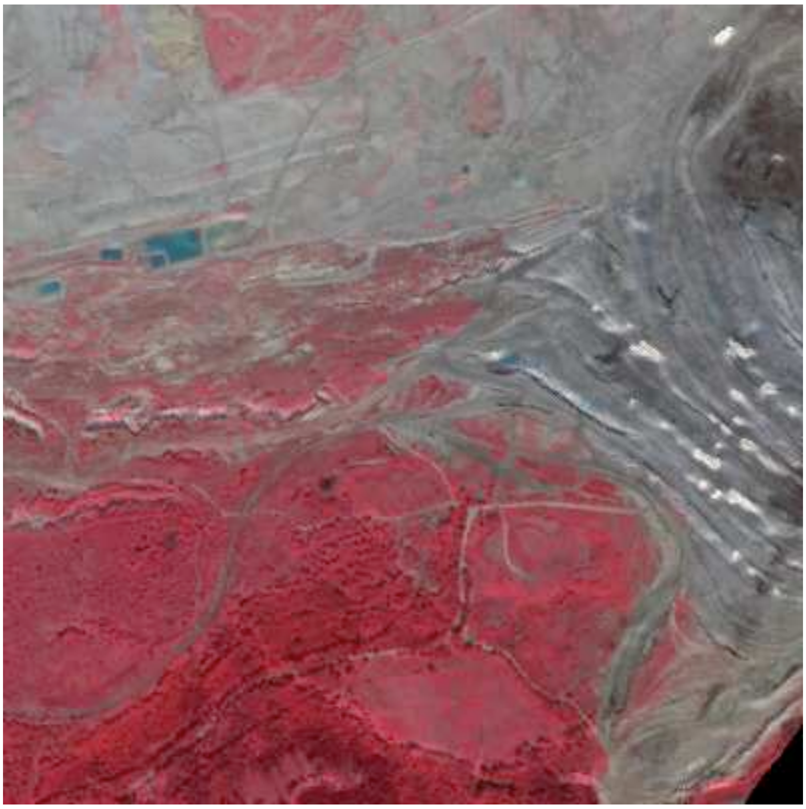


Figure 30: CIR ortho-rectified, atm. and terrain corrected scene. Note the bright overcorrected areas in right part

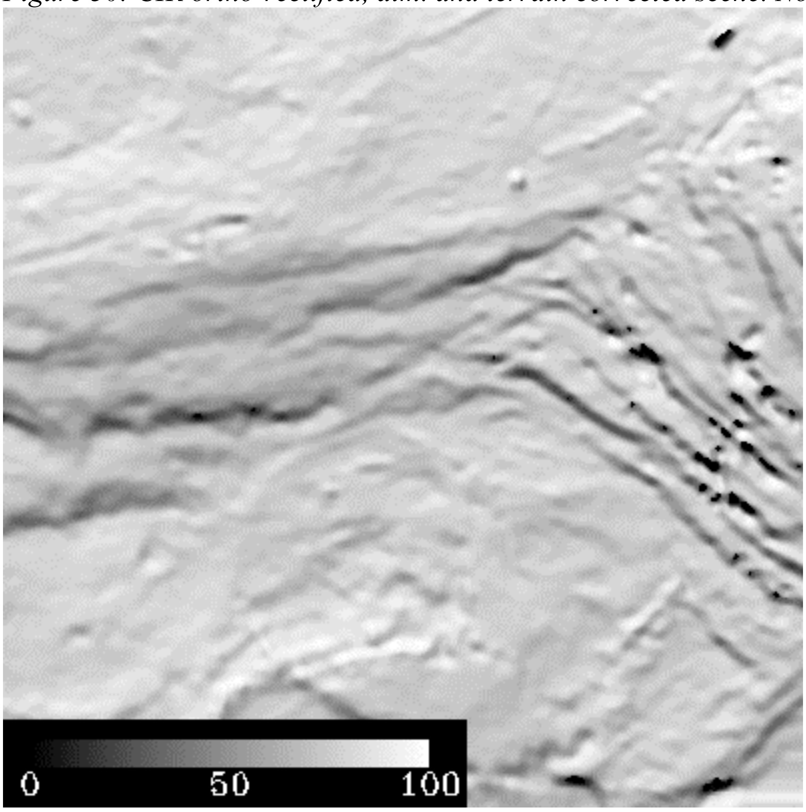


*Figure 31: Illumination (cos. of local view angle * 100). Again, note the artefacts in the right part*

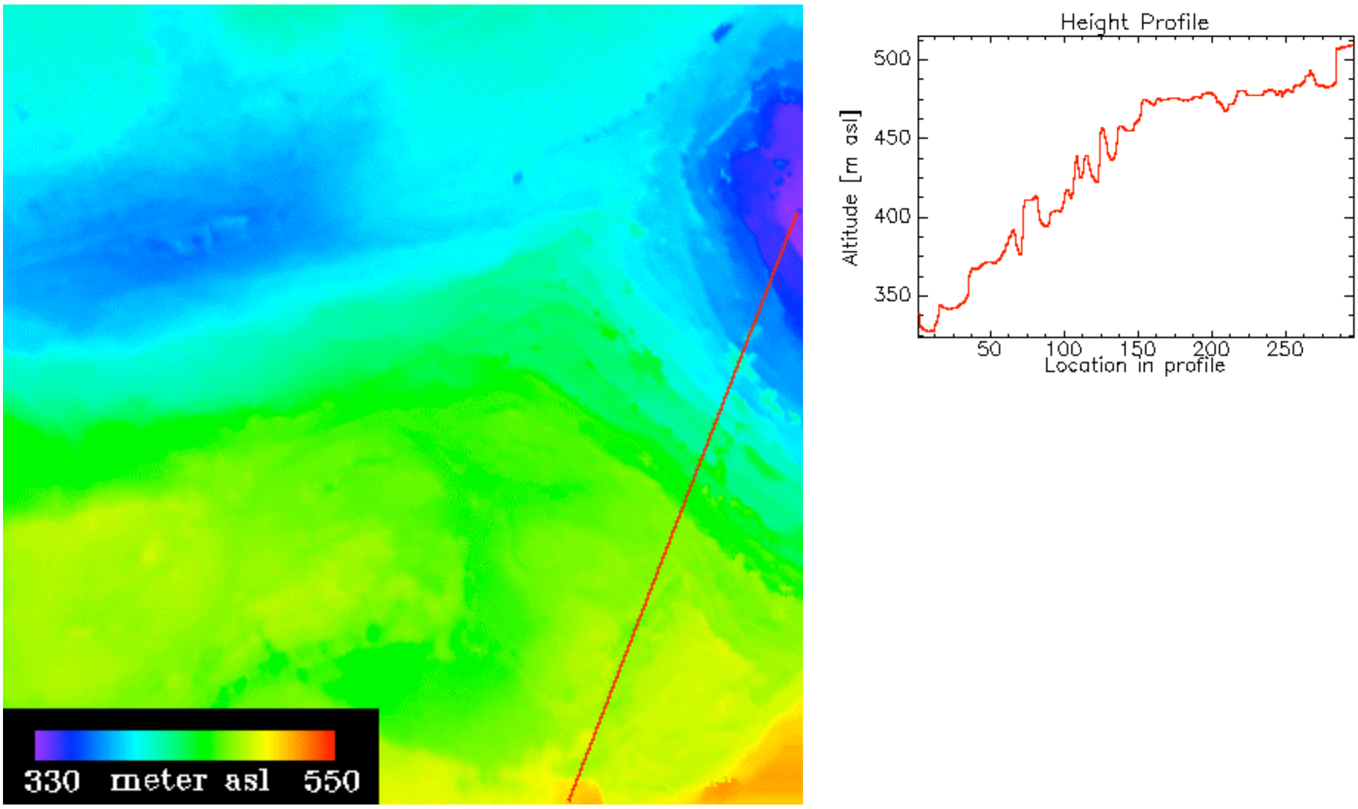


Figure 32: DEM and corresponding height profile (red line in DEM image)

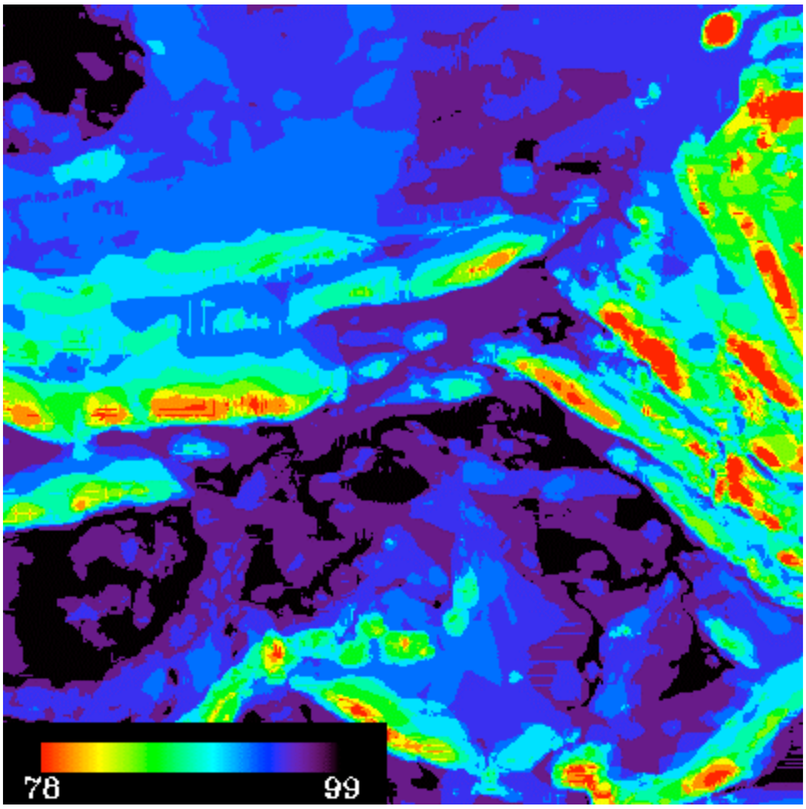


Figure 33: Sky view factor [%]

8 Implementation of Quality Layers at INTA

8.1 Recent developments at INTA PAF

DJ2.1.1, section 8 (table 8.4), details INTA's AHS processing chain. However, this document does not include some recent developments, and does not detail the CASI chain. For this reason, an updated version of Table 8.4 from DJ211 is included below, and a similar table for CASI is also included.

PROCESS-STEP	INPUT	TOOL AUTOMATED	OUTPUT	NOTES
Level 0 to Level 1a processing				
Import from AHS binary files to level L1a image products	AHS binary files in AHS-PC1-*AHSImagery\CCCCCYY\bin*	AHSImportUtility	*image_*.bil* (L0R000) *image_*.hdr* (ENVI) *image_*.csv* *image_*.raw* (ERDAS) + ancillary data	AHSImportUtility is a software design by ArgonST
		Automatic process-step with manual configuration		
Standardization of file names Quality Control Backup L0 Files transfer	*image_*.bil* (L0R000) *image_*.hdr* (ENVI) *image_*.csv* *image_*.raw* (ERDAS) + auxiliary data Campaign configuration file *AHS_YYMMDD_CCCCC.txt*	AHS_rencpy_time.m	L1a images **_L0R000_PTT.raw / .hdr*	AHS_rencpy_time.m is a MATLAB function by INTA The files are transferred from AHS-PC$_1$ to AHS-WorkStation$_n$ (Linux)
		Automatic process-step with manual configuration		
Standardization of file formats Backup L1a	L1a images **_L0R000_PTT.raw / .hdr*	A3	<u>L1a image product</u> **_L0R000_PTT.raw / .hdr* (see L1a description in table 8.1.3)	A3 is an IDL pro design by INTA
		Automatic process-step with manual configuration		
Metadata generation	L1a image product Ancilliary information	createMDfile.m IME	L1a - XML metadata files	createMDfile.m is a MATLAB function by INTA Metadata files according to ISO19115
		Automatic process-step with manual configuration		
Level 1a to Level 1b processing				
Radiometric calibration - VNIR/SWIR Standardization of file formats Backup L1b - VNIR/SWIR	L1a images **_L0R000_PTT.raw / .hdr* Radiometric calibration coefficients including empirical correction factor (fe) and degradation factor (fd)	AHS_rencpy_time.m	<u>L1b image product</u> **_L10020_PT12.raw / .hdr* (see L1b description in table 8.1.3)	AHS_rencpy_time.m is a MATLAB function by INTA See radiometric VNIR/SWIR calibration model in DJ211, section 8.3.1. B/
		Automatic process-step with manual configuration		
Metadata generation	L1b image products Ancilliary information	createMDfile.m IME	L1b_PT12 - XML metadata files	L1b_PT12 - XML metadata files according to ISO19115

PROCESS-STEP	INPUT	TOOL AUTOMATED	OUTPUT	NOTES
		Automatic process-step with manual configuration		
Radiometric calibration - MIR/TIR Standardization of file formats Backup L1b - MIR/TIR	L1a images *_L0R000_PTT.raw / .hdr spectral responsivity of the AHS thermal channels	A3	L1b image product *_L10020_PT34.raw / .hdr (see L1b description in table 8.1.3)	See radiometric MIR/TIR calibration model in DJ211, section 8.3.1. C/
		Automatic process-step with manual configuration		
Metadata generation	L1b image products *_L10020_PT34.raw / .hdr Ancilliary information	createMDfile.m	L1b_PT34 - XML metadata files	L1b_PT34 -XML metadata files according to ISO19115
		Automatic process-step with manual configuration		
Level 1b to Level 1c processing				
Orthorectification	L1b image products *_L10020_PT12.raw / .hdr *_L10020_PT34.raw / .hdr Exterior Orientation file DEM AHS sensor model	PARGE batch	Input Geometry files *_igm.raw/.hdr Angular output *_sca.raw/.hdr Terrain definition (slope/aspect/shadow/skyview) *_slp.raw/.hdr *_asp.raw/.hdr *_shd.raw/.hdr *_sky.raw/.hdr	PARGE is a software design by ReSe
		Automatic process-step		
	L1b image products *_L10020_PT12.raw / .hdr *_L10020_PT34.raw / .hdr Input Geometry files *_igm.raw/.hdr	ENVI batch	L1c image product *_L10022_PT12.raw / .hdr *_L00122_PT34.raw / .hdr	ENVI is a software design by ITT
		Automatic process-step		
Metadata generation	L1c image products *_L10022_PT12.raw / .hdr *_L10022_PT34.raw / .hdr Ancilliary information	createMDfile.m	XML metadata files	L1c -XML metadata files according to ISO19115
		Automatic process-step with manual configuration		
		Manual process-step		
Level 1 to Level 2 processing				
estimation of surface reflectance, temperature and emissivity	L1c image products *_L10022_PT12.raw / .hdr *_L10022_PT34.raw / .hdr Line of sight file *_sca.raw/.hdr Terrain definition (slope/aspect/shadow/sky) *_slp.raw/.hdr *_asp.raw/.hdr *_shd.raw/.hdr *_sky.raw/.hdr	ATCOR4	L2 image product *_L20022_PT12.raw / .hdr *_L0222_PT4T.raw / .hdr *_L0222_PT4E.raw / .hdr	
		Manual process-step		

Table 4: AHS processing chain (updated January 2011)

PROCESS-STEP	INPUT	TOOL AUTOMATED	OUTPUT	NOTES
Level 0 to Level 1a processing				

PROCESS-STEP	INPUT	TOOL AUTOMATED	OUTPUT	NOTES
Import: from CASI raw files to level L1a image products Standardization of file names Quality Control Backup L0	CASI raw binary files (similar to Geomatica-pix BIP format)	macro radcorr	L1a images for quality checks *_L1a.pix* *_L1a_DCU.pix*	csh script executing radcorr (a tool provided by Itres)
		Automatic process-step with manual configuration		
Level 1a to Level 1b processing				
Radiometric calibration and generation of Quality Descriptors	CASI raw binary files in	macro radcorr	Calibrated images, both for quality checks and for further processing *_L1b.pix* *_L1b_DCU.pix* *QD_*.txt*	csh script executing radcorr (a tool provided by Itres)
		Automatic process-step with manual configuration		
Pix 2 bsq Backup L1b	L1b pix images	Specific IDL -ENVI tool	*_L1b.bsq*	
		Automatic process-step with manual start		
Level 1b to Level 1c processing				
Orthorectification and completion of quality descriptors	Exterior Orientation file (SBET) Boresight values *QD_*.txt*	macro SBET	corrected navigation files in Itres format and in ascii Updated *QD_*.txt*	csh script executing several Itres applications (makegps, attsync formnav, navcor)
		Automatic process-step with manual configuration		
	L1b image products *_L1b.pix* DEM CASI internal orientation corrected navigation files *QD_*.txt*	macro geocor	Input Geometry files *_glu.bsq/.hdr* Angular output *_nad.bsq/.hdr* georeferenced images *_L1c.pix* *QD_*_L1c.txt*	csh script executing geocor (a tool provided by Itres)
		Automatic process-step with manual configuration		
Quality Control: statistics and Quality Layers	L1a and L1b products: *_L1a.pix* *_L1a_DCU.pix* *_L1b.pix* *_L1b_DCU.pix*	Specific IDL -ENVI tool		
		Automatic process-step with manual start-up		
Level 1 to Level 2 processing				
estimation of surface reflectance, L1b geometry	L1b image products *_L1b.bsq / .hdr*	ATCOR4	L2b products	
estimation of surface reflectance, L1c geometry	L1c image products *_L1c.bsq / .hdr* *nad files (TBD)*	ATCOR4		TBC

Table 5: CASI processing chain.

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Definition of product levels at INTA PAF (table 8.3 in DJ211) is also to be updated following the integration of CASI products.

L1a	*L1*	**Raw product** – Image product with raw digital counts from the imaged area and from two onboard reference black bodies. 12 bits/pixel. Image product with 80 bands in BIL format + ENVI header and with ancillary information, statistics and radiometric calibration coefficients.	**Raw product** – Image product with raw digital counts from the imaged area and from reference dark and uniform reference frames recorded at the start and end of the scene. 14 bit/pixel. Geomatica pix format (BIP). Variable number of bands.
L1b	*L1*	**User product** - georeferenceable at sensor radiance in nw/(cm2 sr nm). n BSQ format + ENVI header. An Input Geometry Data (IGM) enabling for geometric correction is attached.	**User product** - Georeferenceable at sensor radiance in nw/(cm2 sr nm). BSQ format + ENVI header. An Input Geometry Data (GLU file) enabling for geometric correction is attached.
L1c	*L1geo*	**User product** - georeferenced at sensor radiance, in BSQ format + ENVI header.	**User product** - georeferenced at sensor radiance, in BSQ format + ENVI header.
L2b	*L2atm*	**User product** - georeferenceable hemispherical-directional reflectance factor and kinetic temperature, in BSQ format + ENVI header, usually with Input Geometry Data (IGM) enabling for geometric correction.	**User product** - georeferenceable hemispherical-directional reflectance factor, in BSQ format + ENVI header, usually with Input Geometry Data (GLU) enabling for geometric correction.
L2c	*L2atm+geo*	**User product** - georeferenced hemispherical-directional reflectance factor and kinetic temperature in BSQ format + ENVI header.	**User product** - georeferenced hemispherical-directional reflectance factor in BSQ format + ENVI header.

Table 6: INTA product levels

9 Description of algorithms

9.1.1 Problems with position and attitude information

This quality parameter is applicable for each image line.

It is applicable to L1a, L1b and L2b. For L2c it is required to map the original acquisition geometry (where problems are defined) to the georeferenced grid.

Two types of "problem lines" are flagged:

- gaps. Gaps are frequent at the start and end of AHS images due to a small mismatch between actual image acquisition and the signal sending events from AHS to the POSAV unit. They are unlikely in the CASI images, which do not use the events approach for synchronization of image and navigation records.
- bad quality of position or attitude information due to any reason (including rapid changes, bad GPS coverage and maybe others)

The algorithms to be used are shown in the table below. They are fully equivalent to those defined in section 6.1.

step 1	Create specific layer in the QL file with default value "0"		
type	**gaps**	**rapid changes**	**others**
steps 2:n AHS	annotate events start/end line in image by checking the marker-bit flag for 1:numlines if ((line(i) < events_start) or (line(i) > events_end)) then line(i) = 1 end end	The algorithm in section 6.2 will be used on POSEO files.	open POSEO file for 1:numlines if (position RMS(i) > 1 pix) or (attitude RMS(i) > 1 pix) then line(i) = 1 end end
steps 2:n CASI	NA	The algorithm in section 6.2 will be used on the *.rnv files.	TBC

Table 7: Algorithms to be used for correction

9.1.2 Interpolated position and attitude information

This quality parameter is applicable for each image line.

It is applicable to L1a, L1b and L2b. For L2b it is required to map the original acquisition geometry (where problems are defined) to the georeferenced grid.

This algorithm only applies to interpolation outside the nominal one performed during the synchronization of POSAV measurements and image lines. It is the case of position/attitude data gaps as described in the previous section for AHS; note that it is actually an extrapolation and not an interpolation.

The logic for applying interpolation/extrapolation is outside the algorithm, but defined in the processing procedure. According to it, INTA will fill all data gaps regardless of their size extrapolating position and copy attitude from the first available line, and will not modify lines with rapid changes in position/attitude or high RMS value.

The algorithm will simply check if the line corresponds to a data gap. Currently only the case of AHS data gaps at the start and end of the image is considered. The algorithm is therefore:

step 1	Add a specific layer in the QL file with default value "0" and band name "interpolated_POSAV".
steps 2:n AHS	for 1:numlines if ((line(i) < events_start) or (line(i) > events_end)) then line(i) = 1 end end

Table 8: Algorithm for checking lines corresponding to data gaps

9.1.3 Cloud mask

This quality parameter is applicable for each image pixel.

It is applicable to L1b and L2b. For L2c it is required to map the original acquisition geometry (where clouds are identified) to the georeferenced grid.

There are two separate cases for cloud mask: land scenes and water scenes.

Land cloud mask.

The algorithm defined in ATCOR4 version 5.1 (2010) and described in 6.3.1 is adapted to AHS and CASI images, to be able to run independently of L2b product generation, on the L1b product.

Water cloud mask.

INTA cloud masking over water approach is not operative yet. It could be included as a tool within the N6 Standards and Protocols toolbox, provided it is ready upon deadline.

9.1.4 Cloud shadow mask

Not used in INTA PAF.

9.1.5 Haze mask

Not used in INTA PAF.

9.1.6 Critical local viewing and illumination geometry

This quality parameter is applicable for each image pixel.

It is applicable to all processing levels, but for land surfaces it is naturally computed in the cartographic geometry, where DEM is defined. Therefore, to provide this quality layer in L1 or L2b it is required to perform an inverse mapping to the original acquisition geometry from the georeferenced grid.

The concept of "criticality" here is left to user judgement, based on a set of observation/illumination geometrical parameters that are provided as quality layers. These parameters are computed by different components of the processing chain.

9.1.7 Aggregated bad pixel mask ("not corrected")

According to section 4.1.1. the problems to be included in this QL are:

1. Uncorrected dead pixels on detector
2. Negative radiance / reflectance values
3. Data artefacts

The first problem is due to sensor state / performance during image acquisition and every image pixel originated at a defective detector pixel (specific detector pixel) will be equally affected. Besides, it is only applicable to CASI (pushbroom) imagery. On the other hand, problems b) and c) arise from the combination of sensor performance, scene characteristics and/or atmospheric correction failure.

Following this rationale, INTA PAF has split this QL into two layers, each of them addressing the following problems:

1. Uncorrected dead pixels on detector. Anomalous response of the detector, manifested through anomalous noise or signal, is also checked and tagged. This layer is only applicable to CASI data.
2. Pixels with negative radiance / reflectance and data artefacts. Pixels with zero radiance are also included in this layer. Only data artefacts resulting in zero or negative values of radiance or reflectance are detected. This layer is applicable to AHS and CASI imagery.

QL 1, as defined above, is built from the information registered in the radiometrically calibrated Uniformity Frames (UF) of each CASI image. UF is a set of ≈200 frames registered at the beginning and end of each flight line, with a translucent cover between sensor and scene and can be thought of as a “snapshot” of the condition of the slit at the time that an image file was opened and again upon closure. It is intended to render a uniform signal to the detector, but the underlying scene, as opposed to standard laboratory-based conditions, adds low frequency signal structure. To overcome this influence on the analysis, low frequency structure is eliminated by linearly detrending, on the across track direction, the statistics of the detector on a moving window basis, prior to analysis. To avoid undesirable outlier effects on the quality of the detrending process, outliers in each window are not taken in consideration when computing the detrending parameters.

Anomalous detectors on the CCD are spotted and tagged on a two-fold approximation: on an individual band-pixel base and on an aggregated spectral dimension base.

In the band-pixel approach, for each band, the mean signal (MS) and standard deviation (STD) over a set of UF is computed for every pixel. The resulting series, MS and STD, are linearly detrended on a moving window basis, to eliminate low frequency, resulting in the dMS and dSTD series. The value of these two series on every detector pixel undergoes the following tests and the pixel is flagged according to test results:

anomalous_flag IF dMS(i) LT [median(dMS) – NEdL]
OR dMS(i) GT [median(dMS) + NEdL] Eq 1.2.7.1
anomalous_flag IF [dSTD(i) – median(dSTD)] / 9*MAD(dSTD) GE 1 Eq 1.2.7.2

The test on D-STD follows an outlier detection technique addressed later in this section.

In the aggregated spectral dimension approach, problems common to every band in each detector pixel, not easily detected by the previous approach, due to the low signal registered in the UF, are highlighted by computing the median of the standardized detrended MS and STD series, over the entire spectral dimension, giving series MS-dMS and MS-dSTD. Each of the resulting series, is checked for outliers, following the same procedure introduced in Eq 1.2.7.2. CCD array pixles where more than 50%, at least, of the bands have a bad behaviour are thus, flagged.

anomalous_flag IF [MS-dMS(i) – median(MS-dMS)] / 9*MAD(MS-dMS) GE 1
OR [MS-dMS(i) – median(MS-dMS)] / 9*MAD(MS-dMS) LT -1 Eq 1.2.7.3
anomalous_flag IF [MS-dSTD(i) – median(MS-dSTD)] / 9*MAD(MS-dSTD) GE 1 Eq 1.2.7.4

The outlier detection approach mentioned above, assumes that a bad pixel on the detector or a whole column in it, is an (a number of) isolated event(s) whose performance is not representative of the global performance of the sensor band or the whole CCD array, as previously assessed for each band by the image quality check implemented in INTA's processing chain, and delivered in the CAS_*.stats files. Accordingly, if the overall quality of the band calibration or the radiometric resolution are poor, it will not be detected by this means, as it is assumed that the previous mechanism will do so. The outlier detection technique used is based on robust normalization following Wilcox, 1997[1].

This layer is distributed in two geometries:

1. Raw image geometry: image pixels are tagged with the accumulated sum of bad pixel bands.
2. Spectral geometry: band pixels with anomalous behaviour are tagged with "1".

QL 2, as defined previously, is built from a simple radiometric check of the at-sensor radiance in AHS and CASI bands (L1b product), according to equation 1.2.7.5. Note that detection of data artefacts, if not generating a negative or zero radiance, is not implemented.

zero_flag IF Ls(ij,k) LE 0 Eq 1.2.7.5

In the resulting QL, pixels are flagged with the accumulated sum of bands where the zero flag is raised. If the L2b product (reflectance) is delivered, this test is also applied and results are stored in a separate QL for the reflectance product.

[1] Rand R.Wilcox, 1997. *Introduction to Robust Estimation and Hypothesis Testing* (Academic Press)

9.1.8 Aggregated interpolated pixel mask ("corrected")

This quality parameter is applicable to each image column in CASI images; it is not applicable to AHS images.

This algorithm flags the pixels previously detected as anomalous with “1” where data has been corrected and “0” elsewhere, resulting in two QLs, one in raw image geometry and another one in spectral geometry.

9.1.9 Saturated pixel / overflow

Quality parameter applicable to each image pixel, both for AHS and CASI imagery.

Pixels are considered saturated if their DN (level L1a) equals the maximum value permitted by the instrument digitization (equation 1.2.9.1). After overall image statistics computation, bands whose maximum value in the image is detected to be equal to such a maximum are spatially checked to find the pixels where this value occurs.

The resulting QL, is a layer with the number of band saturation occurrences per pixel.

Saturation thresholds (μ_0) for INTA’s sensors are:

AHS: μ_0 = 2^12-1=4095
CASI: μ_0 = 2^14-1= 16383

saturated_flag IF ND(ij,k) EQ μ_0 Eq 1.2.9.1

9.2 Integration in processing chain

Quality Layers will be created by different SW elements within the INTA processing system. Some of them are still under development. The following table associates each algorithm with the corresponding SW element.

Remark: QL are not applicable to L0 due to the different size of the actual image files and the L0 files, which include ancillary information.

Algorithm	SW element in AHS chain	SW element in CASI chain
Problems/ Interpolated position	AHS_rencpy and POSPAC for detection (outputs in marker-bit log and POSEO errors column respectively). Specific tool within A3 for generation of the QLayer and detection of rapid changes.	CASI QA tool on L1c processing.
Problems/ Interpolated attitude	As above.	CASI QA tool on L1c processing.
Cloud mask over land	Specific tool within A3 for generation of the QLayer on L1 processing.	CASI QA tool on L1 processing.
Cloud mask over water	NA	NA
Cloud shadow mask	NA	NA
Haze mask over land	NA	NA
Haze mask over water	NA	NA
Critical local viewing and illumination geometry	Details on implementation TBD.	Details on implementation TBD.
Aggregated bad pixel mask ("not corrected")	Specific tool within for generation of the QLayers.	CASI QA tool on L1 and /or L2 processing.
Aggregated interpolated pixel mask ("corrected")	Specific tool within for generation of the QLayers.	CASI QA tool on L1 processing.
Saturated pixel	AHS_rencpy_time	CASI QA tool on L1 processing.

Table 9: Algorithm and its corresponding SW element in AHS and CASI chain

Quality layers for AHS and CASI are provided as ENVI files, i.e, binary files with a descriptive text header with specific pairs [label=value]. The filename is the same as the image name but replacing the processing level and port suffixes with suffix QA and a code for the processing level (see table below).

	Image File	QL file
AHS	AHS_yymmdd_hhmmZ_P####	AHS_yymmdd_hhmmZ_P####_QAL.bsq
CASI	CAS_yymmdd_hhmmZ_P####	CAS_yymmdd_hhmmZ_P####_QAL.bsq CAS_yymmdd_hhmmZ_P####_QA_CCD.bsq

Table 10: Image file and QL file

Band names in the quality layers files above will be compatible with the description of the quality layers provided in this document (Section 4.1).

QL not used in INTA's PAF quality assessment, will not be included in the QL file, rather than including them as an *NA* layer.

Flow charts with a draft view of the integration of quality analysis tools in the processing chain of AHS and CASI are shown in the figures below.

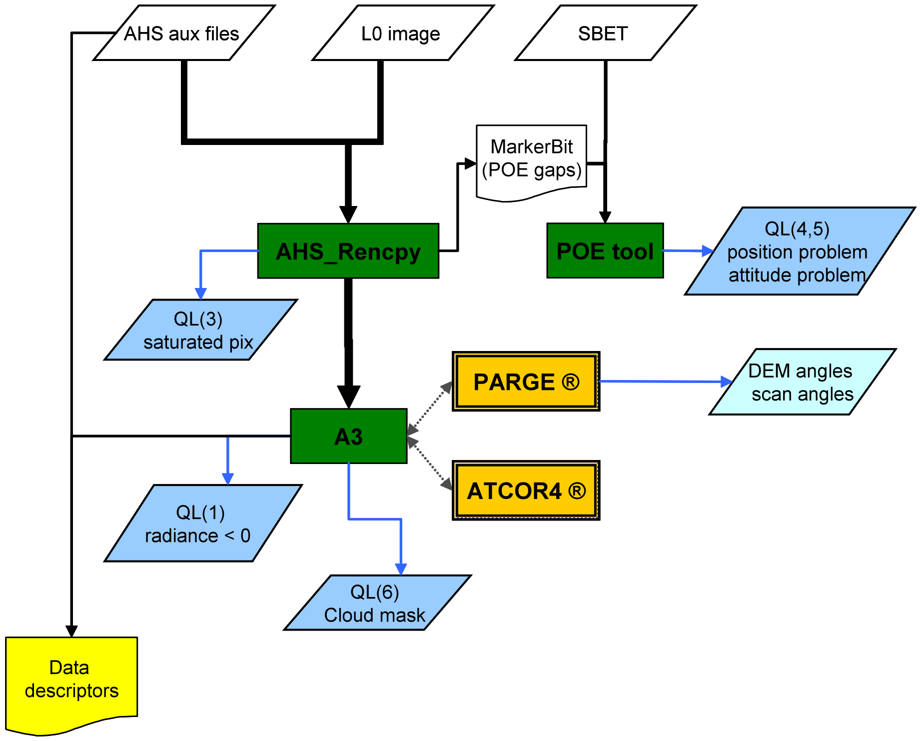


Figure 34: Integration of QA tools in the INTA-AHS processing chain.

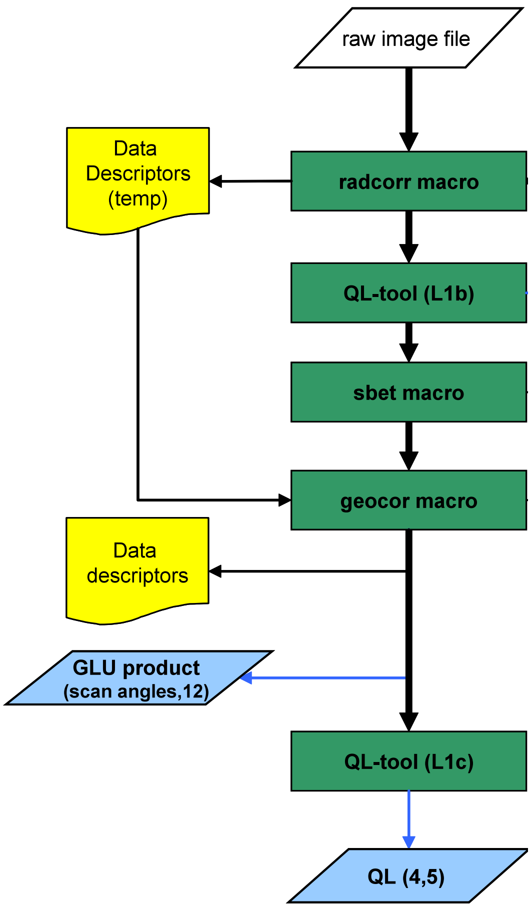


Figure 35: Integration of QA tools in the INTA-CASI processing chain.

9.3 Examples for Quality Layers and Data Descriptors

Quality layers for AHS and CASI are provided as ENVI files, i.e, binary files with a descriptive text header with specific pairs [label=value].

The filename is the same as the image name but replacing the processing level and port suffixes with suffix QA and a code for the processing level (see examples in the table below).

Sensor	Image File	QL file
AHS	AHS_yymmdd_hhmmZ_P####_L10020_PT12.bsq	AHS_yymmdd_hhmmZ_P####_QALb.bsq
CASI	CAS_yymmdd_hhmmZ_P####_L1b.bsq	CAS_yymmdd_hhmmZ_P####_QALb.bsq

The figures below display two examples of INTA-PAF quality layers.

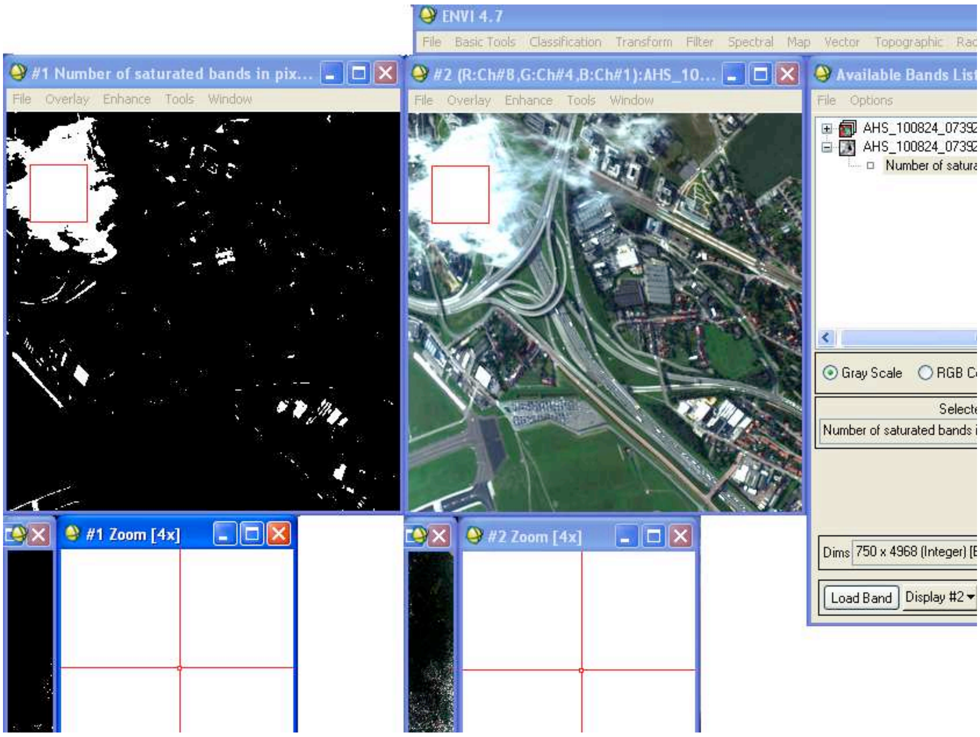


Figure 36: AHS saturated pixels.

Figure 8.3:

Figure 37: CASI BadPixel-Zero radiance count

Figure 8.4:

10 Implementation of Quality Layers at PML

10.1 Recent developments at PML PAF

10.1.1 In house radiometric calibration

For late 2010 and early 2011, an in-house calibration was conducted. This marks a departure from past practice of using the manufacturer calibrations. While the change was prompted by a manufacturer mistake in the 2010 Hawk calibration, an in-house calibration has been an objective for a while. With this, numerous additional tests can be performed, the instrument better characterised and the documented. Analysis of the data is ongoing, but has already led to a new procedure for bad pixel detection, described below.

10.1.2 Bad pixel detection

During radiometric calibration, an estimate is made of the quality of sensor pixels. Multiple measurements are taken (e.g. different integration times) with 100-1000 frames to allow averaging, using two light sources (a well-known integrating sphere and a sphere with a calibrated blue filter). The tests below are run on these multiple datasets and results aggregated. Each test defines a number of times a pixel must fail a test before it is considered as a bad pixel.

Whenever a threshold value is mentioned below, two numbers will be stated – the first is for the unfiltered sphere and the second for the sphere with the blue filter. The thresholds generally have to be different to accommodate the responsiveness of the sensor to the different light characteristics.

Our program has 4 methods currently defined and used during bad pixel detection on calibration data, the fifth listed is a post-filter.

- Constant Input Variable Output (CIVO)
- Constant Input Constant-Invalid Output (CICO)
- Linear Input Non-Linear Output (LINO)
- Rapid Saturation (RS)
- Cross-Method Failure

The first two methods, CIVO and CICO, detect bad pixels according to their response during a constant input and therefore each of these tests are run on each input file individually. The second two methods, LINO and RS, look at the linearity and the slope of pixels respectively. This requires them to take an input set of files that differ in their integration times and so the responses of the pixels are expected to correspond linearly with the different integration times.

10.1.2.1 Method description: Constant Input Variable Output

Parameters:

- *μ of CCD pixel , average response of CCD pixels in DN*
- *σ of CCD pixel , standard deviation of response of CCD pixels in DN*

Method CIVO calls pixels bad when they vary significantly given a constant light. This is done by considering their average DN μ and the standard deviation σ, which are taken through time. Using σ and μ, both in DN units, the relative standard deviation of a pixel can be given as:

σ *of CCD pixel /* μ *of CCD pixel*

which then is compared to the constant threshold CIVOthreshold and when that threshold is exceeded the CCD pixel is called bad.

CIVOthreshold (Upper): (0.025,0.02)
Number of required failures before marking bad: 1

10.1.2.2 Method description: Constant Input Constant-Invalid Output

Parameters:

- μ *of CCD pixel, mean value*

Method CICO calls pixels bad when their response to a constant light greatly varies from the response of their spatial and/or spectral neighbours. Of the three main measures taken from each file, the one required here is the average DN. To determine when a pixel's response varies it has to be compared to its close neighbours. A scanning window is used to detect responses that differ significantly.

The scanning window, which takes the shape of a diamond or a vector, has a spatial width of CICOspatialwidth (39,39) and spectral width CICOspectralwidth (1,1). To measure how much a pixel varies from its neighbours, it's absolute distance is taken from the average of all the values within the scanning window. To put that distance into context, it is turned into a number of standard deviations away from the average of the scanning window. That value is given as;

μ *of CCD pixel* −
(μ *window centred at(sample,band) /* σ *window centred at (sample,band))*

When the above value exceeds CICOscalar then the bad-counter for this pixel is incremented.

CICOscalar (Upper): (7,9.5)
Number of required failures before marking bad: 2

10.1.2.3 Method description: Linear Input Non-Linear Output

Parameters:

- μ *of CCD pixel, of all given linear files*

Method LINO looks for pixels that respond non-linearly to linear increases in the input light. It takes the averaged Digital Number (DN) 2D arrays of all available datasets. These are ordered with increasing integration times, which should correspond to increasing sensor response in a linear fashion. The integration time becomes the third dimension, which may or may not be in equal intervals between each file.

Now the linearity is examined per pixel per band, but only once for all files, which is the difference of this linear method from methods CICO and CIVO. The Pearson Product-Moment Correlation Coefficient (PPMCC) will be calculated using X,Y = (integration time IT, μ of CCD pixel) values and will return a value to indicate the quality of the best linear fit (the closer to 1.0 the better the fit). The formula is given as;

$$\left(\sum_{i=1}^{N} \frac{(X_i - \mu_X) * (Y_i - \mu_Y)}{N * \sigma_X * \sigma_Y} \right)^2$$

with X as the integration times and Y as the μ of CCDpixel . The lower thresholds for the output Pearson's coefficient are LINOpearsonsthreshold below. Since with this method each pixel is tested only once, regardless of the number of files, if it fails then it has failed this method.

<u>LINOpearsonsthreshold (Lower):</u> (0.995,0.9975)
<u>Number of required failures before marking bad:</u> 1

10.1.2.4 Method description: Rapid Saturation

Parameters:
- *slope of CCD pixel through all given linear files*
- *slope of μ of CCDpixel through all given linear files*

This method seeks to detect pixels that achieve saturation significantly earlier (or much later) than their neighbours. While they will be usable for some operational settings, they may be unreliable in others.

Method RS works similarly to CIVO in order to detect linear but invalid responses to different integration times. This method uses the slopes of the best linear fit on points with X,Y = (IT, μ of CCD pixel), as in LINO. Once again, a scanning window of spatial width (39,39) and spectral width (1,1) will iterate over each pixel of each band. If the slope at the centre of the window, which is being tested, varies greatly in relation to its neighbours, then the pixel in that position will be called bad. The function used to scan over each pixel is the same one used in CIVO, and the formula is the same;

slope of CCDpixel −
(μ of window centred at(sample,band) / σ of window centred at (sample,band))

When the above value exceeds the threshold then the pixel will be called bad. One fail suffices to fail this method.

<u>SLOPEscalar (Upper):</u> (6,8.5)
<u>Number of required failures before marking bad:</u> 1

10.1.2.5 Method description: Cross-Method Failure

This method simply identifies pixels that have partially-failed multiple tests, but not enough to mark the pixel as bad in any one test.

<u>Number of required failures before marking bad:</u> 2

10.1.3 Progress in automation

A new script has been written to automatically download and format data from the aircraft after a flight. This significantly reduces the person-time required following a flight and also eliminates a large source of errors. The script also now automatically creates flight logsheets showing each data line in a context, along with all the necessary information.

Finally, a KML file is now produced when data are acquired and is updated as processing proceeds, allowing the commissioning users to see the status of a project visually as well as giving the opportunity for rapid feedback in the event of problems (e.g. a site of interest being covered by a cloud and requiring a refly).

10.1.4 Processing chain re-engineering

A significant re-engineering of the processing chain has been undertaken since late 2010 in order to address some licensing concerns. The overall structure of the system is broadly unchanged, but the opportunity has been taken to incorporate HYQUAPRO developments as work progresses. The first milestone for a complete version is the 2011 flight season, beginning April.

10.2 Description of data QC algorithms

10.2.1 Problems with position and attitude information ; Interpolated position and attitude information

PML have implemented an approach equivalent to that described in Chapters 6.4 and 6.5.

10.2.2 Cloud and other masks

PML does not produce level 2 products and has not committed to implementing a cloud mask. As such, no masking was implemented and no descriptions of the common approach was available. Now the descriptions of the common algorithms are available, PML will aim to implement them. An issue is that the Eagle and Hawk instruments have different fields of view, so that the required spectral bands may only be available in the central overlap region.

10.2.3 Aggregated bad pixel mask ("not corrected")

In the NERC PAF, “bad” pixels are marked as such by zeroing them out and are not interpolated at level 2 or below (so there is no mask for “corrected” bad pixels). During geocorrection, the interpolation process ignores marked-bad pixels and will thus implicitly interpolate across gaps caused by bad pixels.

Bad pixels in the NERC PAF result from either an unusable sensor pixel or from saturation/underflow. Bad sensor pixels are available as a mask in ENVI BIL format, as well as being zeroed out in processed data. Saturated or underflowed pixels are also zeroed out. An aggregate bad pixel mask can therefore be derived by summarising zeroed pixels in the processed datacube.

10.2.3.1 Bad sensor pixels

During radiometric calibration, an estimate is made of the quality of sensor pixels. A pixel may be marked as “bad” according to the criteria in 10.1.2.

10.2.3.2 Underflowed and overflowed pixels

Overflowed (saturated) pixels are trivially detected by pixel values being at the maximum digital number for the instrument (4095 for Eagle, 16383 for Hawk).

At the end of each acquisition, the Specim Eagle and Hawk automatically close a physical shutter and record a specified number of “dark frames” with no exterior illumination. Underflowed pixels may then be detected by their digital number being below the average (modal) value recorded for that pixel in the “dark frames”. Typically these only occur on the Hawk instrument.

10.2.3.3 Pixels affected by saturation in spatial / spectral neighbourhood:

The quality of pixels spatially or spectrally neighbouring a saturated pixel can be reduced for sensor designs based on frame-transfer CCDs (e.g., AISA Eagle). Thus these pixels are detected and included in a separate mask (see below).

10.2.4 Synchronization problem

This quality layer was converted to a data descriptor (estimate of remaining timing uncertainty following manual correction / visual inspection).

However, it can still be converted to a quality layer by running the processing through to produce two GLT files (giving positions of pixels) for the possible extents of the synchronization error. These GLT files can then be differenced, which will give a per-pixel map of potential positional error due to synchronization uncertainty, and would demonstrate simple uncertainty propagation.

10.2.5 Pixels affected by saturation in spatial / spectral neighbourhood

The Specim Eagle uses a frame-transfer CCD, which shifts image data into a temporary storage buffer line by line. During this shifting process, light continues to fall on the CCD and is registered as a smear from the first line read to the last line (in Eagle's case, this is across the spectral dimension, from red to blue). Hawk uses a different detector technology and is unaffected.

This additional light can be compensated for by removing a fraction of the light recorded by previous rows. This amount can be computed as a fraction, F, of the measured value. Assuming the incoming light does not change (significantly), the fraction will be only dependent on the time to shift a row into the read out electronics. So, for a read out time, Tr, and measurement integration time, I,

$$F = Tr / I$$

For a given single spatial pixel at band y with an accumulated value of Ay, the corrected value Cy is given by:

$$Cy = Ay - (Sum\ [b = y\ to\ 0]\ Pb * F)$$

For example,

$$C3 = A3 - (C2*F + C1*F + C0*F)$$
$$C4 = A4 - (C3*F + C2*F + C1*F + C0*F)$$

However, when a pixel saturates, any additional incoming light will go unrecorded. As such, following pixels can no longer be accurately corrected for smear. In the NERC PAF, pixels spectrally following a saturated pixel are zeroed out. The aggregated bad pixel mask will include these pixels. If a separate full datacube is desired, it can be generated by scanning the level 0 file for saturated pixels and marking all spectrally-following pixels as affected by saturation in the spectral neighbourhood.

Additional work has been undertaken on characterising errors due to smearing of data in unrecorded regions of the CCD. For example, when a subset of bands are recorded, the light falling on the unrecorded areas of the CCD cannot be compensated for during smear correction. PML has characterised the likely scale of these errors and will include a textual report on them with datasets.

At present, NERC does not have measurements detailing the effect of spatial and spectral bloom (how much a pixel is affected, optically or electronically, by the values of nearby pixels). NERC intends to measure this if time, equipment and a successful experimental design are available. TAU have stated it is approximately 3 pixels in Specim instruments.

10.2.6 Critical local viewing and illumination geometry

The following data layers are available and cover the requirements as described in Chapter 6.9:

- sensor position in grid coordinates, Units: m
- sensor position lat/long on WGS84 spheroid, Units: dec degs
- sensor height above WGS84 spheroid, Units: m
- pixel position in grid coordinates, Units: m
- pixel position lat/long on WGS84 spheroid, Units: dec degs
- pixel height above WGS84 spheroid, Units: m
- pixel slope and slope azimuth, Units: dec degs
- view vector azimuth and zenith pixel to sensor, Units: dec degs
- distance pixel to sensor, Units: m
- solar illumination vector azimuth and zenith, Units: dec degs
- solar incidence angle to pixel surface, Units: dec degs

10.3 Integration in processing chain

The quality indicators for saturated pixels, bad sensor pixels and their aggregation into a single bad pixel mask are already in place and available. Similarly, a datacube for pixels affected by saturation in the spectral neighbourhood (due to smear) can be generated as required.

Navigational problem flagging is implemented in the new processing chain.

Cloud masking is an optional extra for the NERC PAF and will be considered for future implementation.

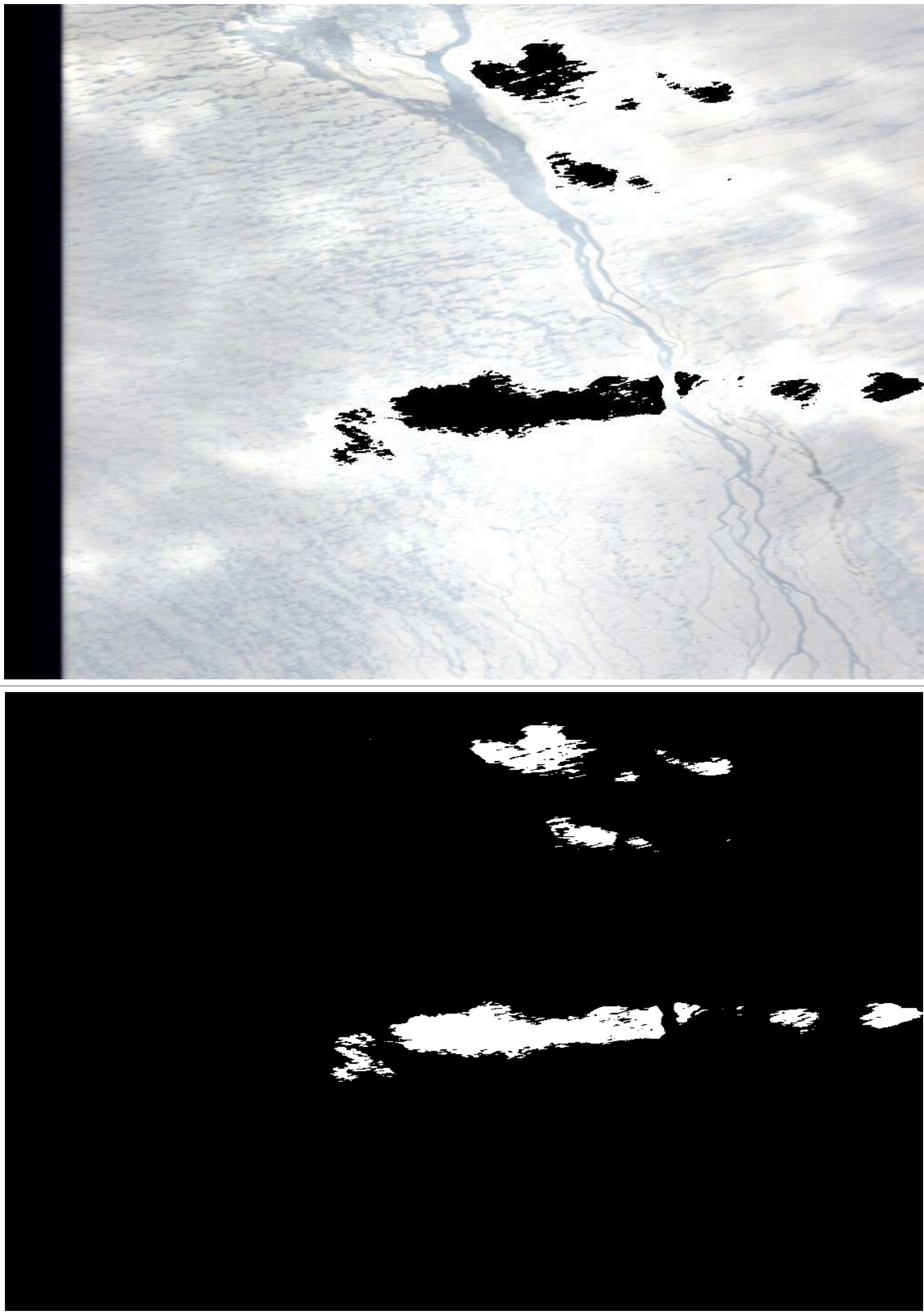
Positional error due to synchronization uncertainty is also an optional extra, but PML wish to implement this as it is a relatively straightforward product and demonstrates a significant part of the JRA output. This will be done in future.

Viewing and illumination geometry is available along with the geolocation (IGM) file.

10.4 Examples for Quality Layers and Data Descriptors

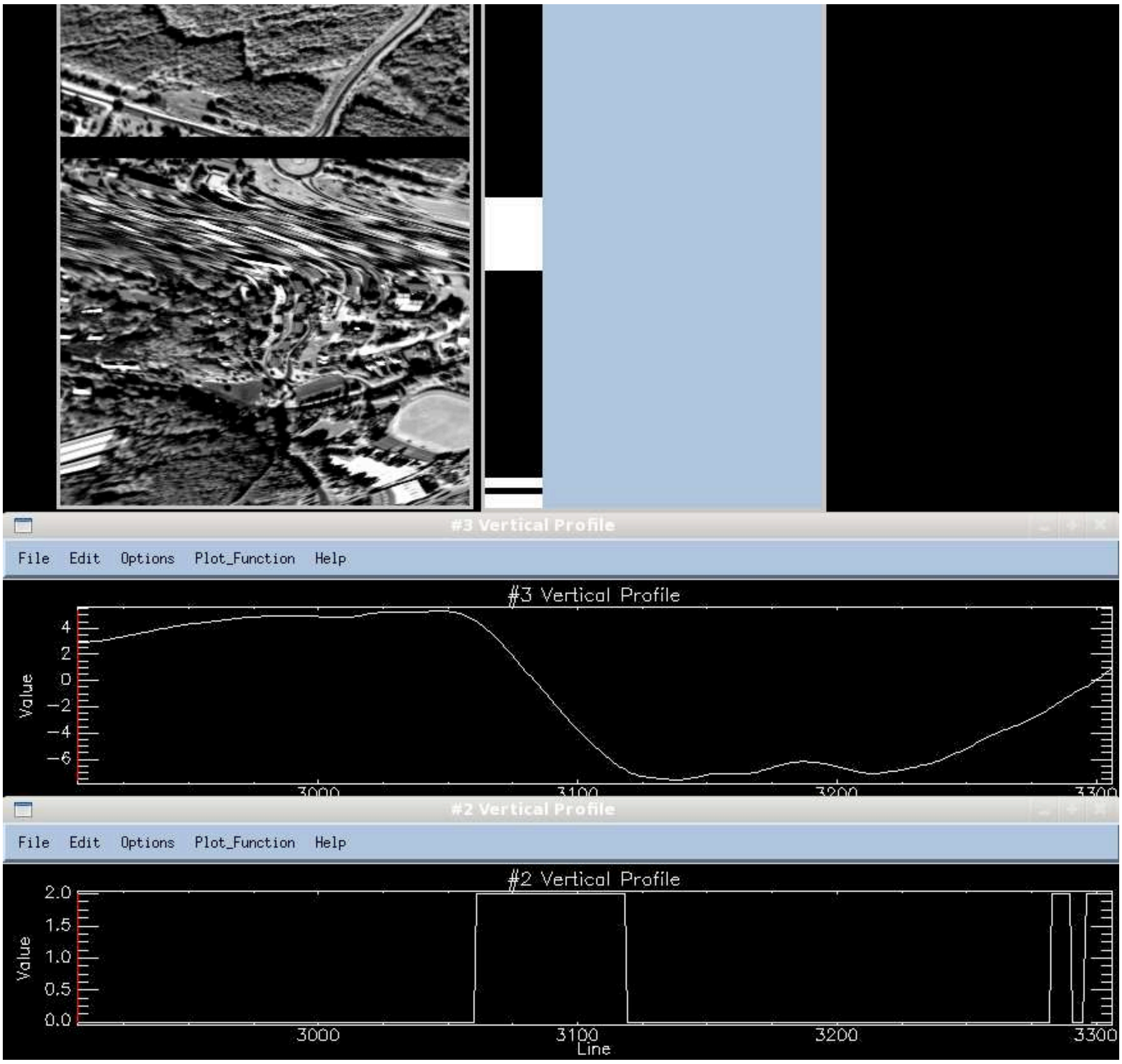
At present, the quality indicators are available in a number of forms (mostly ENVI BIL format). This is easily translated to the EUFAR HDF5 container format, although without an internal specification of the contents, this is merely a repackaging.

Metadata, including data descriptor, are produced in ISO-19115 compliant XML format. This XML conforms to the available specifications, though many aspects of the presentation are undefined. In these cases, judgement of the best fit to ISO was used in choosing a presentation.



Saturated Eagle imagery from IPY07/10 and the associated aggregated bad pixel mask.

10.5



A flightline with a sharp roll with the navigational problem vector highlighting this area. The first plot is of the roll and the second is the navigation vector.

11 Implementation of Quality Layers at VITO/UZH

11.1 Recent developments at VITO/UZH PAF

11.1.1 End User Data Documentation

Goal of the end user data documentation generation is the compilation of existing data descriptors and processing options into a document that is concise and easily readable by the end user. Generally, all information to be included is present after data processing, but is spread over several different files, mostly in a format, which is neither visually appealing for nor semantically readily understandable by the end user.
The following information is included in the end user data documentation:

Section	Subsection	Information
Introduction	-	Campaign
		FLT Line Number
		Date(YYYYMMDD)
		Start/End Time (UTC)
		Avg. Altitude [m asl]
		Avg. Heading [deg]
		Start Lat/Lon [deg]
		End Lat/Lon [deg]
		Number of frames (along track dimension)
		Image Cube Filesize
Applied Processing	Level1 - Data Calibration	Radiometric calibration
		Bad Pixel replacement
		Negative radiances treatment
		Frown
		Smile
		Spatial coregistration of detectors
		Dark current correction
		Destriping
	General remarks and known Data Issues	Radiometric calibration
		Bad Pixel replacement
		Negative radiances treatment
		Frown
		Smile
		Spatial coregistration of detectors
		Dark current correction
		Destriping
APEX PAF Module Versions	Level0 - Raw Data Processing	Name and version of main modules
	Level1 - Radiometric/Geometric/Spectral Data Calibration	
	Quality Layer Creation	

Processing options, whose states are represented by Boolean values, are to be presented to the user as prose. Such prose can be prepared in advance for each Boolean option, defining the descriptive text to appear for the states of TRUE and FALSE but also remarks that are added in all cases, i.e. irrespective of the Boolean value. An example for the bad pixel replacement is given below.

State	TRUE	FALSE	TRUE OR FALSE
Prose	Bad Pixel replacement by spatial linear interpolation	Bad pixels were not interpolated	Some bad pixels could not be corrected and were set to NaN. Please refer to the frame quality layer to identify the affected pixels.

The compilation process is designed in a generic fashion to achieve to following goals:

- Prose can be easily changed, i.e. no hard coding
- New processing options can be added to the prose list without necessitating recoding
- Documentation is structured into sections and sub-sections
- Documentation can created in various output formats, in a first version as simple text file, without requiring a reimplementation of the compiling routine

The prose is contained in a formatted text file, giving the text for the three cases and specifying the corresponding calibration option by the XML tags. For the MINUS_RAD_SUBS calibration option, the entry in the calibration options prose file looks as follows:

Section	Option Tag	TRUE	FALSE	TRUE OR FALSE
CALIBR	MINUS_RAD_SUBS	Negative radiances, typically appearing in water vapour absorption bands, have been set to zero.	Negative radiances may appear in the calibrated data, mainly in wavelengths areas of very low solar irradiance due to atmospheric transmission.	Radiances in known water vapour bands should be treated with care. Depending on the processing options, they may be set to zero when being negative after radiometric calibration.

New Boolean calibration options are added to the report by including their XML tags and prose text in the calibration options prose file.

The usrdoc module is based on object-oriented design, consisting of a main routine and several classes, which are shown in **Error! Reference source not found.**. The interactions of the main routine and the objects are shown in **Error! Reference source not found.**:

1. The main routine ax_usrdoc creates an ax_usr_doc_class object
2. The ax_usr_doc_class object reads the calibration options prose from a corresponding file
3. The prose texts per calibration option are stored in cal_option_info objects. ax_usr_doc_class holds a list with all cal_option_info objects and indexes them as either included options or missing options, depending on whether the options were switched ON or OFF during processing.
4. The compile method of ax_usr_doc_class creates instances of subclasses of the ax_repblock_class. These hold the actual information, which is to be presented to the user. Some of the report blocks, such as titles and section headings, are hard coded, while others are filled with information taken from existing metadata structures, such as the APEX PAF XML controlling file and the session log file. The calibration option prose held by ax_repblock_class in a list is automatically converted into report blocks. In a last step, the PAF log files are parsed to generate a list of software modules and their versions used during the processing of the dataset, grouped by processing level. ax_usr_doc_class thus holds a list of the report blocks and their sequence

within the list is equivalent to their position in the end user documentation file.

5. The write_txt method call the get_txt method on all report blocks and writes the returned strings to the output text file. Due to the class design, each class renders their text automatically, e.g. section titles are underlined or list items are preceded by their list number.

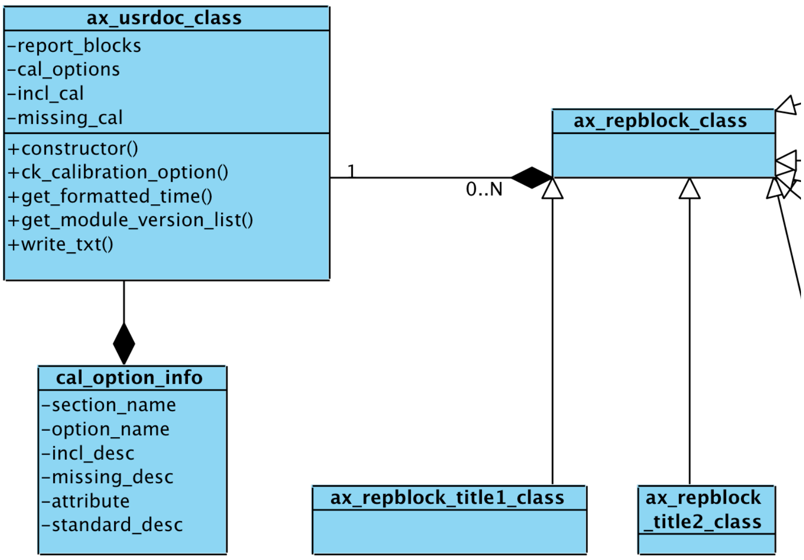


Figure 38: User documentation module classes

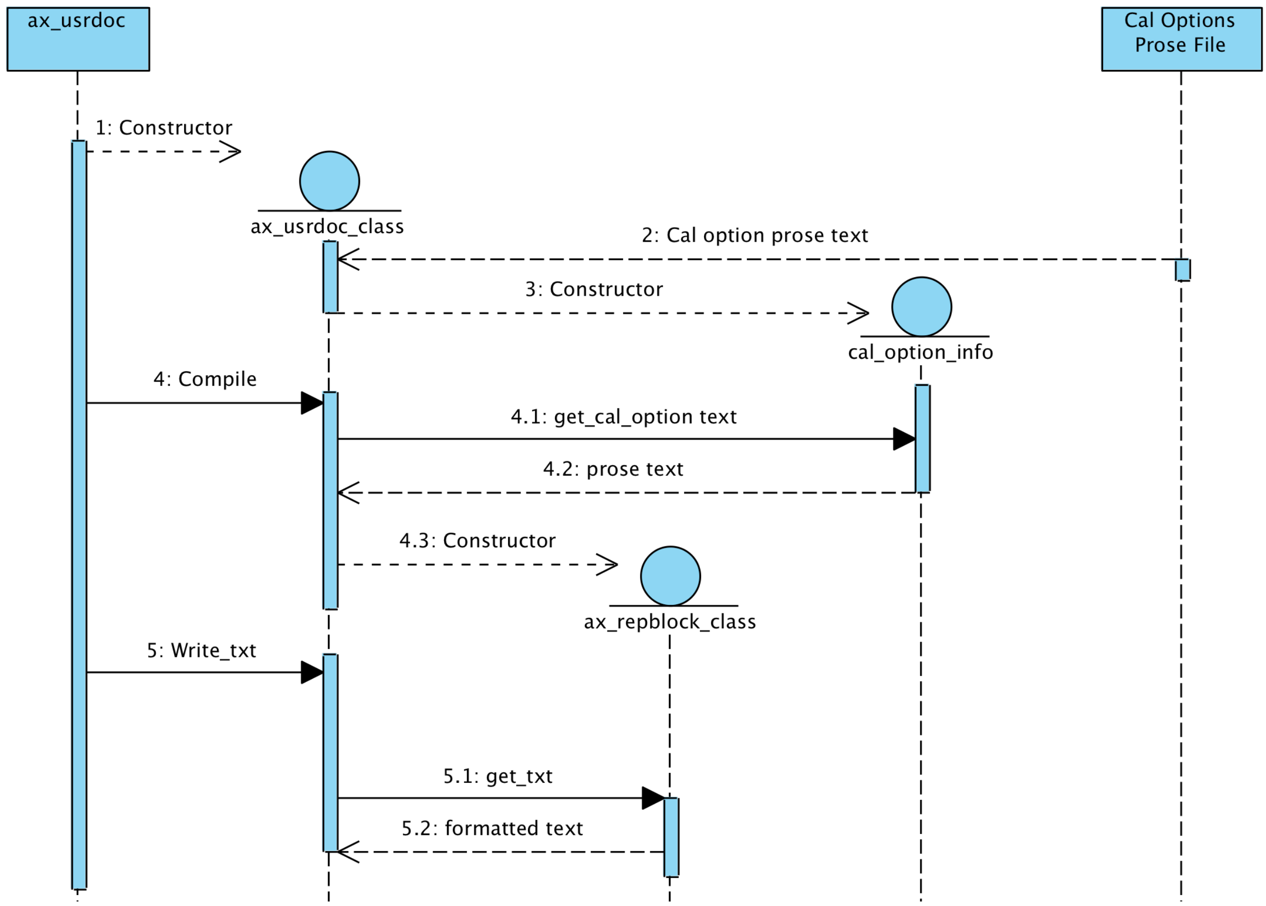


Figure 39: Sequence diagram showing the interactions between main routine and objects

11.2 Description of algorithms

11.2.1 Position and attitude information

This section groups the items “problems with position and attitude information” and “interpolated position and attitude information” sections.

Nowadays, an airborne line scanner is by default equipped with an GPS and IMU system. The GPS system registers position and altitude at 1Hz, an IMU system measures the attitude changes typically at 200 Hz. By combining the GPS and IMU time series and the GPS base station time series in a Kalman filtering process a Smoothed Best Estimated Trajectory (SBET) is created.

For the APEX sensor this Kalman filtering is done by means of the APPLANIX POSPac software. During the filtering, the accuracy of the resulted SBET is calculated. For the APEX June 2010 campaign the results are represented in **Error! Reference source not found.**:

- The North, East and Down Position errors are given in RMS meter (typically most of the time lower than 5 cm).

- The solution status, processing mode, preferably 0 or 1, typically most of the time 0, which indicates a good SBET solution.

- Roll, Pitch and Heading errors are given in RMS arc-minutes (typically most of the time lower than 0.5 arc-min).

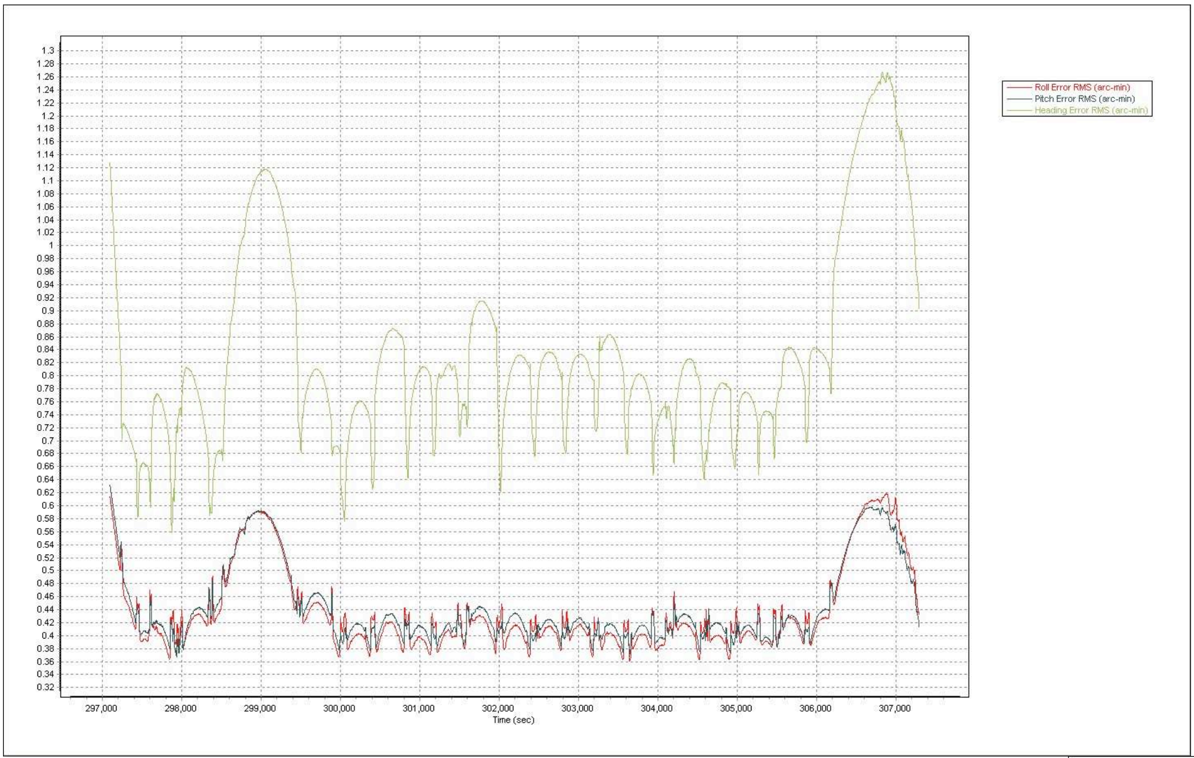


Figure 40: Roll, Pitch and Yaw accuracy [arc-min] for the flight over Belgium 23/06/2010.

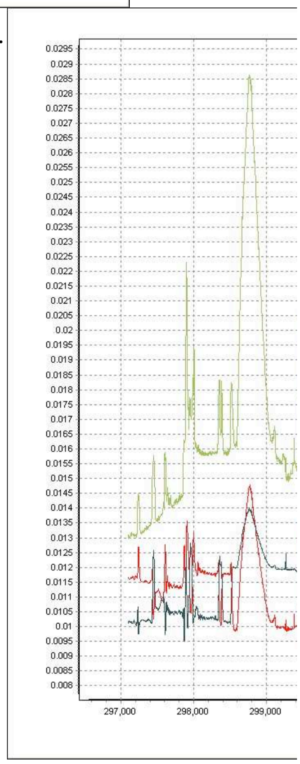


Figure 41: North, East and Down position accuracy [m] for the flight over Belgium 23/06/2010.

In the VITO calibration verification processes (Figure 52), the standardization of the SBET solution towards a format ready for archiving is executed. This standardization process will be updated to also take into account the position and attitude quality layers, i.e. the RMSE values. During this standardization, the RMSE values will also be translated towards uncertainty in RMSE pixel ground position (averaged per scanline). As such, per image not only a “theImage.SBET” file will be created but also a “theImage.SBET.RMSE” reporting the mean RMSE values about (a) camera position, (b) camera attitude en (c) pixel ground position.

11.2.2 Cloud and haze mask

The simplest approach to cloud detection in a scene is the use of a set of static thresholds (albedo, temperature). Unfortunately, these thresholds are sensor specific and have to be tuned by means of a decent number of reference images. Furthermore, these threshold methods can fail for several reasons, such as high reflectance surfaces, pixel dependent illumination and observation geometry, the variability of the spectral response of clouds.

Methods based on the spatial structure have an advantage over threshold methods because they use the local spatial structure to determine cloud free and cloud covered pixels. However, spatial coherence methods are also not fail-proof when dealing with multilayered cloud systems or the scene presents cloud features which are not opaque.

For quantitative masking of cloud and haze features, it is thus difficult to propose a method that is sensor generic. However, if the QL requirements allow for "relative haze and cloud masking" only then the algorithm can be used as presented in Richter (2010)[1] . This is the same algorithm as described in section 6.8.

Preliminary test of this algorithm indicates that the "Haze Optimized Transform" can not only be used to select the haze over land, but is also capable of marking the cloud contaminated areas, as shown in Figure 42. But since (a) the empirical nature of this algorithm and (b) the sensor-specific band spectral properties, it is important to remark that if the "Haze Optimized Transform" (HOT) gets accepted for haze/cloud masking, this QL shall be made available "AS IS", without converting the HOT values to physical decisions whether a pixel is effectively contaminated with haze or is effectively a cloud pixel. The HOT algorithm fails on high reflectance surfaces (snow, water viewed under specific viewing geometry, saturated areas, ...).

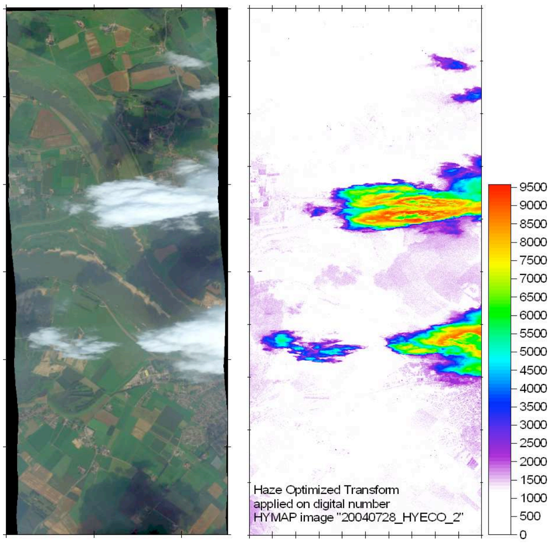


Figure 42. Haze Optimized Transform (HOT) applied on the digital numbers of a HYAMP image (common dataset image).

If appropriate spectral bands are available, an alternative for cloud masking can be provided by means of spectral similarity methods. For an overview of the spectral similarity methods,

1 *Richter, R. 2010. Atmospheric/topographic correction for airborne imagery. ATCOR-4 user guide, version 5.1*

reference can be made to van der Meer (2005)[1]. A result of this technique is presented in Figure 44. For this example, the reference spectra were pooled from the HYMAP imagery as part of the common dataset.

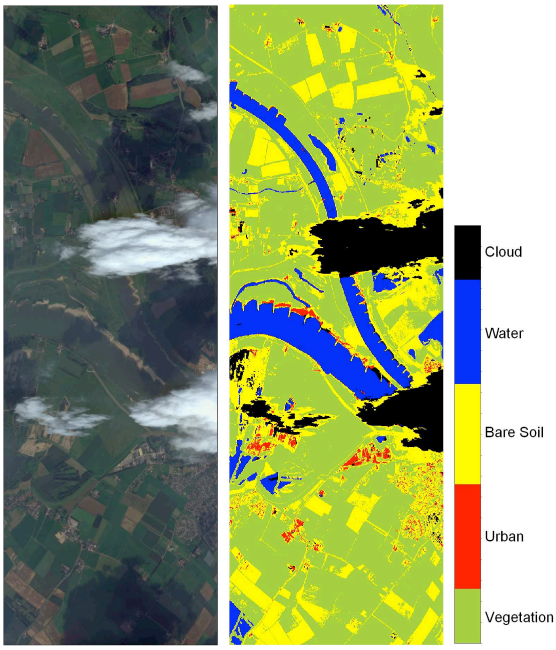


Figure 44: Cloud masking by means of spectral similarity.

For cloud masking a number of other more complex alternatives exist, such as (a) the combination of an unsupervised classification method with a labelling mechanism or (b) a supervised classification method based on a training dataset manually pooled from the imagery from the current or a imaging previous campaign.

However since the HOT method only needs a blue and red band, it is a sensor generic method and can be proposed to supply a qualitative (not quantitative) QL.

11.2.3 Shadow mask

For shadow masking the algorithm will be used as described in Richter (2010)[2]. This is the same algorithm as described in section 6.8. An example of this method is presented in **Error! Reference source not found.**.

However, since this algorithm needs SWIR bands, the method is not generic. As such, this QL can only be generated if the camera band settings fit the algorithm requirements.

Organizers of hyperspectral imaging campaigns should consider equipping the airborne platform with an additional off-the-shelf digital SLR camera. Current SLR cameras can be interfaced with a GPS interface allowing for an easy integration of the imagery in commercial block bundle adjustment software. As such, a low cost solution can be offered to simultaneously capture frame imagery. If frame imagery is available with 60% overlap in the flight-line and 30% overlap between the flight lines, it is possible to extract a digital surface model from the parallax information. An example is given in Figure 47. It is then possible to

1 *Van der Meer, F. 2005. The effectiveness of spectral similarity measures for the analysis of hyperspectral imagery. International Journal of Applied Earth Observation and Geoinformation.*

2 *Richter, R. 2010. Atmospheric/topographic correction for airborne imagery. ATCOR-4 user guide, version 5.1*

easily classify cloud features and to retrieve their elevation (even transparent clouds). Using ray-tracing techniques, which are standard applied during orthorectification, it becomes possible to map the occluded and shadowed areas irrespective the band settings of a sensor. Furthermore, a DSM product is a very important co-variable in any land-classification sheme.

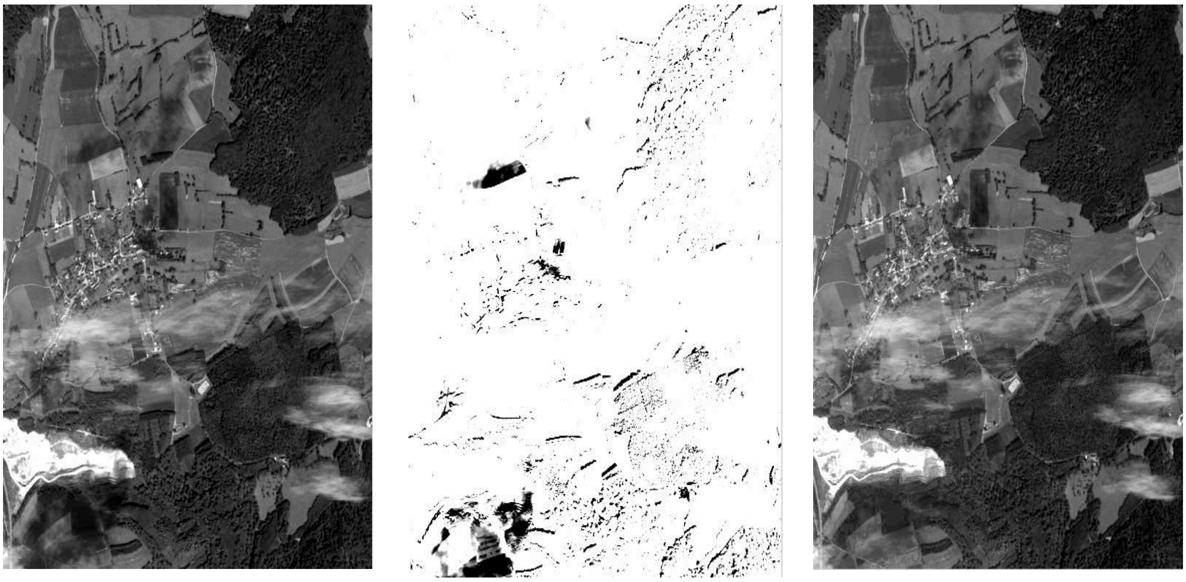


Figure 44. Shadow correction applied on a HyMap scene with the VITO PAF. Left: original, middle: shadow mask, right: shadow corrected.

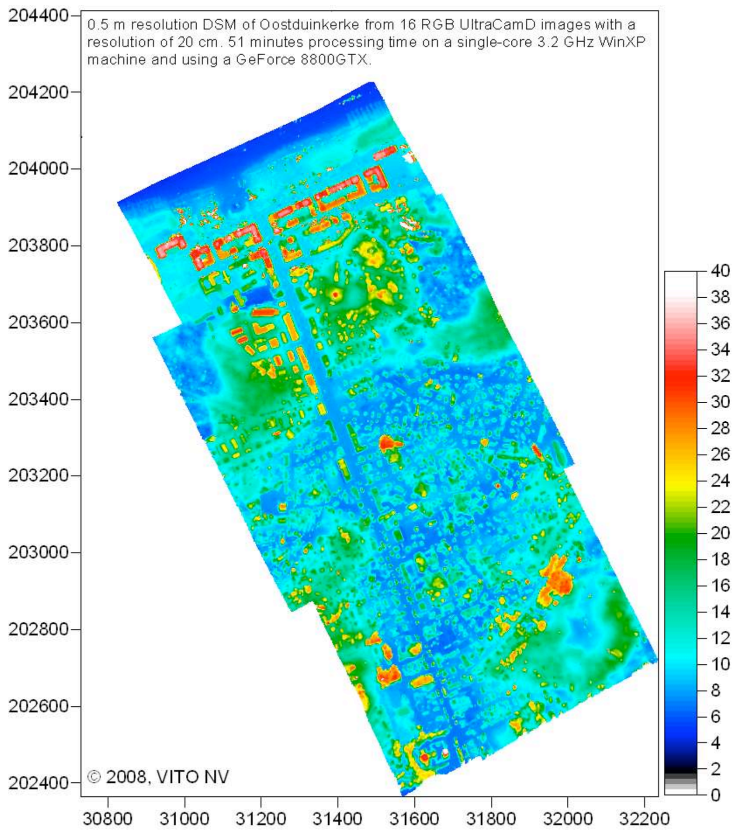


Figure 47. Example of a DSM generated from frame imagery.

11.2.4 Critical BRDF geometry identification

The VITO approach is described in Chapter 6.8

11.2.5 Aggregated bad pixel map (“not corrected” and “corrected”)

A bad/interpolated pixel map is not always available. In this section, an overview is presented on what is available for the APEX camera system.

The *bad pixel* quality layers comprise three different layers, which are extracted from the calibration cubes:

- A bad pixel map containing all bad pixels identified under CHB (Calibration Home Base) conditions
- A map containing all bad pixels that were interpolated during the data calibration
- A map containing all bad pixels that were set to NaN during data calibration

The bad pixel quality layers are stored as layers in the frame quality indicator cube.

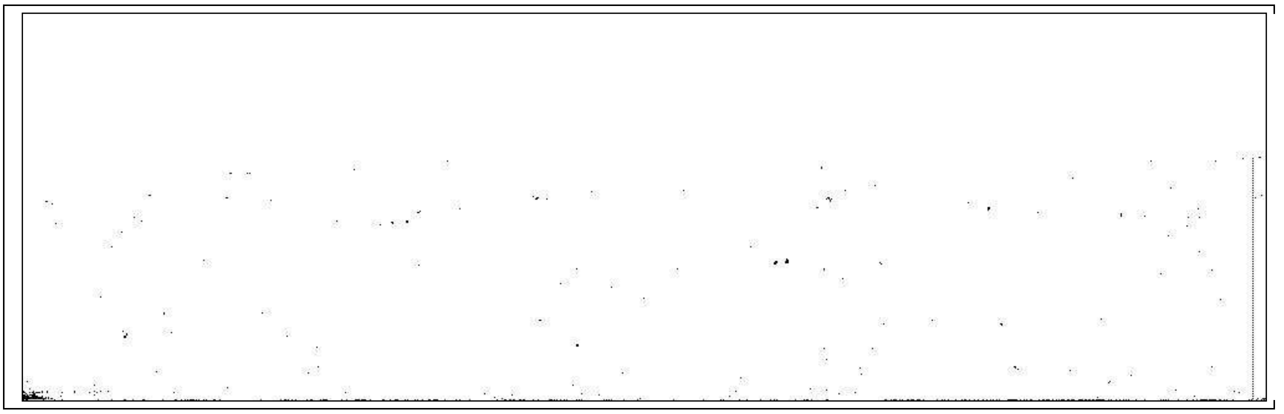


Figure 46 Bad Pixel Map (CHB based)

Figure 47 Interpolated Bad Pixel Map

Figure 48 Bad Pixels set to NaN

11.2.6 Satured pixel/overflow

Saturation detection depends on the definition of thresholds and is thus sensor specific. In this section an overview is presented focused on the APEX camera system.

The thresholds (corresponding to VNIR binned, VNIR unbinned and SWIR) are given in DN and set in a configuration file.

In a first step, a frame mask is created, containing the 90% values of the saturation levels defined in the configuration file.

In a second step, the mask is subtracted from every frame; pixels with (subtracted) values above zero are identified as saturated.

Effectively, the saturation detection per frame renders Boolean values (1 : DN>=sat_level*0.9) ; 0 : DN<sat_level*0.9)

This frame information is accumulated in two ways:

c) An accumulated count in along track direction, yielding a final frame that contains the number of times a spatial/spectral pixel was saturated.
d) An accumulated count in spectral direction, yielding a spatial map with the pixel values being equal to the total count of saturated spectral pixels for each spatial position.

Figure 53 and Figure 55 shows spatial and frame views of the saturation quality indicator, calculated for an APEX scène tuned for water targets, therefore, many land features are registered as saturated pixels.

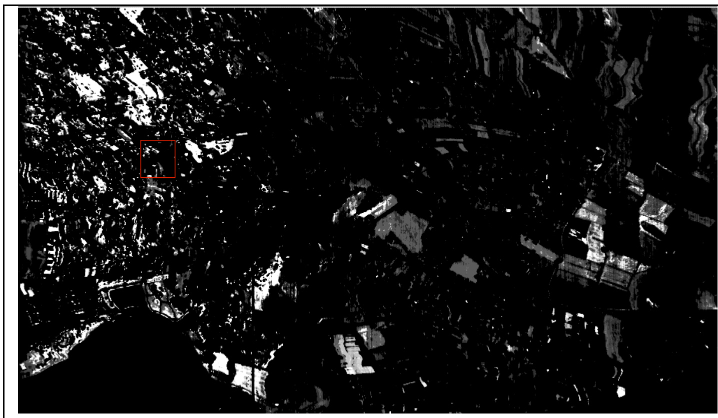


Figure 49: Spatial saturation indicator: accumulated count of saturated pixels per spatial position.

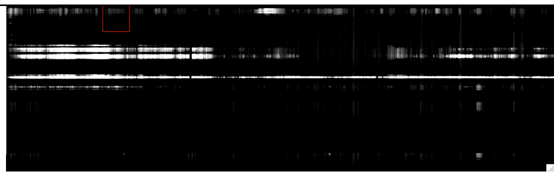


Figure 53: Frame saturation indicator: accumulated along track count of saturated pixels per spectral/spatial position.

11.3 Integration in processing chain

The overall processing system is capable of processing raw incoming airborne imagery up to Level4 information products. For an overview of the image product definitions reference can be made to **Error! Reference source not found.**. Figure 55 to Figure 54 present an overview of the processes involved in the processing of airborne imagery from raw up to the Level 4 information products.

These processes are subdivided in three major groups:

1. Group 1: camera system calibration, verification and archiving. This group of processes results in standardized Level1 products.

2. Group 2: all processes involved in the Level1 to Level2 image production.

3. Group 3: all processes involved in the production of higher level image or information products.

Level 1 image product	**Raw user product** – Level 1 data products are reconstructed, unprocessed instrument data at full resolution, time-referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters, e.g., platform ephemeris, external and internal sensor orientation parameters, computed and appended but not applied. A bitmap quick look is added to the archive file; any and all communications artifacts, e.g. synchronization frames, communications headers, duplicate data are removed. Platform/sensor exterior orientation is enhanced using GPS base station information, and/or is the result from a block bundle adjustment process. Consequently, the Level 1 file is a completely self-descriptive file, enabling for a full radiometric, atmospheric and geometric correction.
Level 2 image product	**User product** – Level 2 data products are geometric and atmospheric corrected sensor values of individual scenes, resampled according user request.
Level 3 image product	**User product** – Level 3 products are Level2 data products mapped on uniform space-time grid scales (i.e. Level2 mosaics), usually with some completeness and consistency and are the result of combining multiple scenes to cover the user's ROI.
Level 4 image product	**User product** – Level 4 data products are model output or results from analyses of lower level data (Level2 or Level3), e.g. variables derived from multiple measurements.

Table 11: Product level definitions.

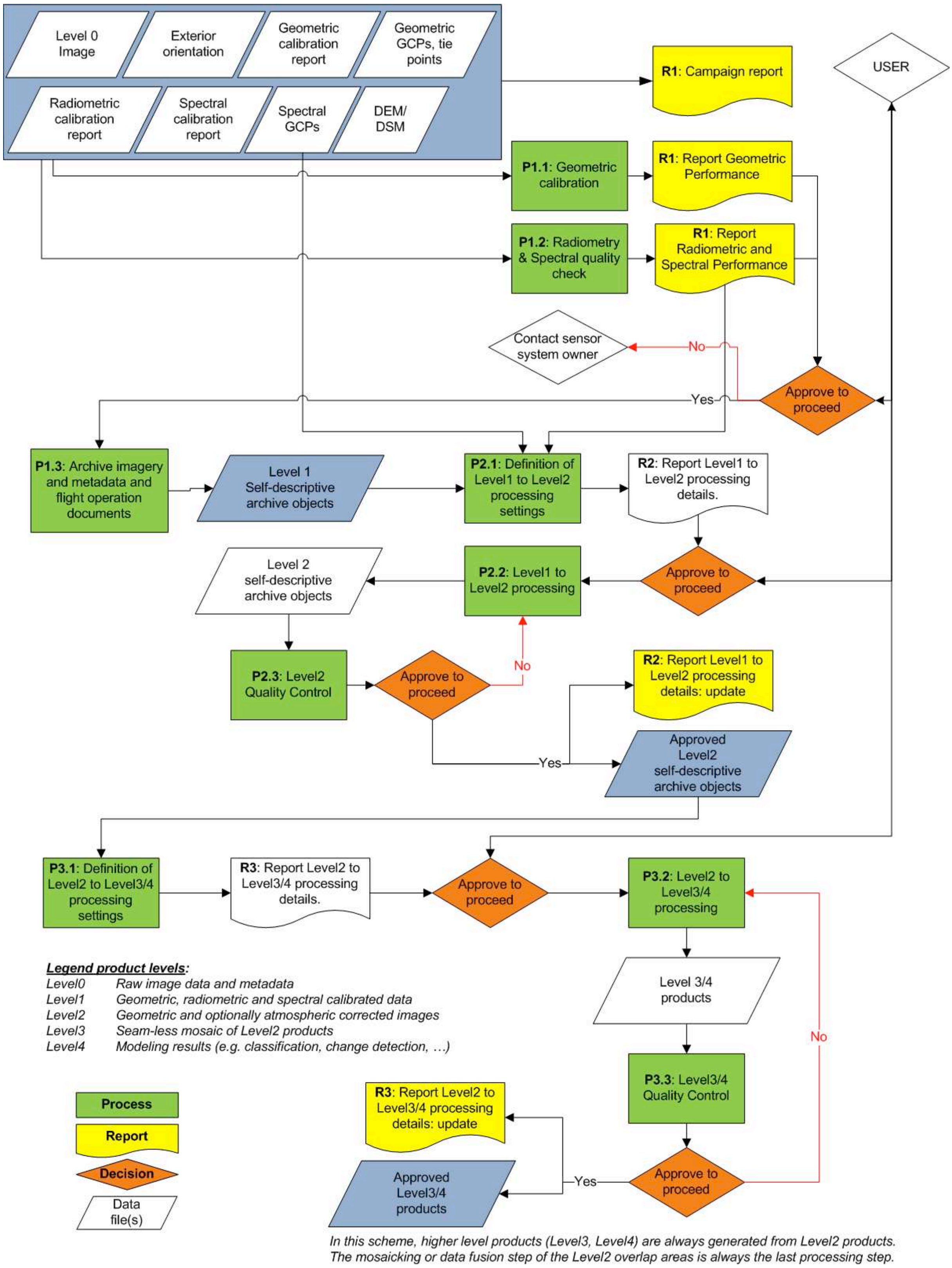


Figure 55. Overview of the processes, reports and decisions in the overall airborne remote sensing workflow

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11.3.1 Calibration and verification

Figure 52 to Figure 54 present a flow chart of the sub-processes involved in the calibration, verification and data archiving phase. Here we suppose that following geometric, radiometric and spectral calibration tasks are already executed: (a) Kalman filtering of the GPS and IMU time series with additional accuracy enhancement by using GPS base station time series in the Kalman filtering process, (b) block bundle adjustment in case of photogrammetric missions, (c) laboratory measurements of the camera interior orientation parameters and (d) laboratory measurements of the radiometric and spectral properties of the camera system.

For photogrammetric camera systems there is usually no radiometric and spectral performance report. Since this is not essential for most applications with this type of data, this is not a workflow-blocking factor.

Unfortunately, for hyperspectral imagers, the geometric and/or radiometric and/or spectral metadata is often of very poor quality. The geometric, radiometric and spectral calibration verification procedures described here are then not only used for verification, but also for correcting the actual calibration.

The calibration and verification processes are executed by operators having the necessary scientific background. The overall calibration and verification process is thus infested with manual operations and a difficult decision making processes in case of calibration problems.

As indicated in Figure 55, the calibration and calibration verification processes result in a report "R1" containing following sections: (1) Campaign Report, (2) Geometric Performance and (3) Radiometric and Spectral Performance.

The "Campaign Report" section will report the 29 Common Data Descriptor QIs:
1. Provider and contact information; 2. File name / unique ID; 3. Campaign name; 4. Site name; 5. Basic sensor characteristics; 6. File name – raw data; 7. File name – quality layers; 8. Laboratory calibration information; 9. Data of radiometric calibration; 10. Data of spectral calibration; 11. Radiometric calibration file used; 12. Radiance units and scale factors; 13. Date and start and end times of acquisition; 14. Platform; 15. Sensor; 16. GPS/IMU; 17. Number of spectral bands (spectral mode); 18. Across track spatial resolution; 19. Along track spatial resolution; 20. Frame rate and integration time; 21. Overall heading; 22. Overall altitude ASL; 23. Solar zenith and azimuth during acquisition; 24. Report on anomalies in data acquisition; 25. Processing level; 26. Processor ID, SW names & versions; 27. Date and time of processing; 28. Dark current correction; 29: Synchronization Problem;

The geometric and the radiometric/spectral verification actions are described hereunder. Because the report "R1" describes the overall camera system performance it is thus a major quality information source for the user.

Verification of the geometric calibration

To verify and standardize the camera interior (focal length, principal point, field of view, slit functions, radial and tangential distortion parameters) and exterior orientation (X, Y, Z, omega/roll, phi/pitch, kappa/yaw and boresight angles) parameters, VITO executes by default a geometric calibration verification (Figure 52 and Figure 53). The results of all these sub-processes are logged in a report labeled R1 in Figure 55.

Ideally, the incoming data consists of: the raw images, an estimation of the exterior orientation (X, Y, Z, omega/roll, phi/pitch, kappa/yaw), a camera geometric laboratory calibration report, a camera radiometric and spectral laboratory calibration report, a set of geometric tie-points and ground control points, a set of spectral ground control points (i.e. in-situ ASD spectral measurements), a digital elevation model, a digital surface model.

The VITO software system uses the USGS GCTP[1] package for the coordinate projection. This package is encapsulated in a C++ interface developed at VITO and allowing for the addition of other projection systems not known by GCTP. For all datum transforms, the VITO software system uses the 7 parameter Helmert transformation. It is a system requirement that the exterior orientation and the DEM/DSM used for orthorectification are in the same projection system and projection datum (Figure 52). This might require a re-projection of the exterior orientation and/or the DEM.

Four country specific projection systems and datum shifts, the C++ framework can be updated ad hoc (Figure 52). These updates are then unit-tested against known coordinate transformation examples published by the national geodetic institutes. The results of this process are logged in report R1.

In support of (a) the camera geometric calibration, (b) the production of orthorectified products and (c) the production of higher level classification or modeling products, following auxiliary data layers are integrated in the image processing workflows:

- The EGM96[2] geoid model. For direct georeferencing in the GPS coordinate system, the geoid is needed to retrieve the local geoid height which has to be added to the local DEM/DSM height.

- Within Flanders: the AGIV LIDAR DEM is used by default for the orthorectification and geometric calibration procedures. This DEM is distributed by AGIV (http://www.agiv.be/) at a spatial resolution of 5 meter and a vertical accuracy of 7 cm for areas covered with short grass or under pavement and 20 cm for areas under complex vegetation.

- Outside Flanders:
    - User supplied LIDAR DEM
    - the SRTM DEM[3] (the Shuttle Radar Topography Mission at a spatial resolution of 90 m) will be used as fallback mechanism if no detailed DEM is available.
    - The NOAA “GLOBE” global DEM[4] (1 km spatial resolution) is used as fallback mechanism to determine the mean elevation over the area covered by the image in case the SRTM DEM contains invalid or no data.

Besides the quality layers about the exterior orientation “problems with position and attitude” and “interpolated position and attitude” (Figure 52), the geometric calibration verification processes also generate quality information about the point accuracy by taking into account both the exterior and interior orientation parameters (Figure 53).

1 http://edcftp.cr.usgs.gov/pub//software/gctpc/

2 F. G. Lemoine, S. C. Kenyon, J. K. Factor, R.G. Trimmer, N. K. Pavlis, D. S. Chinn, C. M. Cox, S. M. Klosko, S. B. Luthcke, M. H. Torrence, Y. M. Wang, R. G. Williamson, E. C. Pavlis, R. H. Rapp and T. R. Olson. 1998. The Development of the Joint NASA GSFC and NIMA Geopotential Model EGM96, NASA Goddard Space Flight Center, Greenbelt, Maryland, 20771 USA, July 1998. (available at: http://cddis.nasa.gov/926/egm96/egm96.html)

3 available at: http://srtm.usgs.gov/

4 available at: http://www.ngdc.noaa.gov/mgg/topo/globe.html

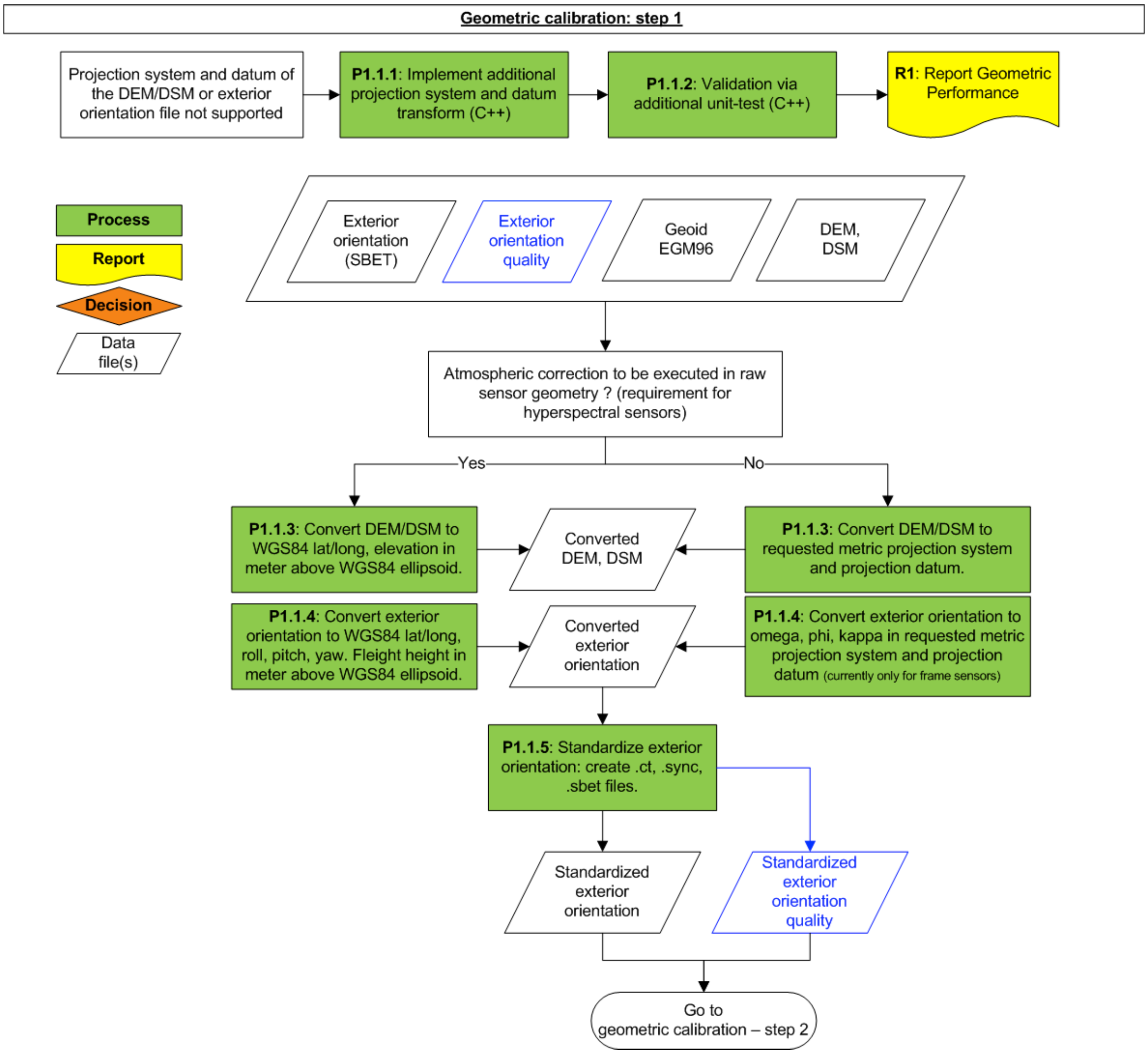

Figure 52. Processes involved in the geometric calibration. The quality layers related with position and attitude are marked in blue.

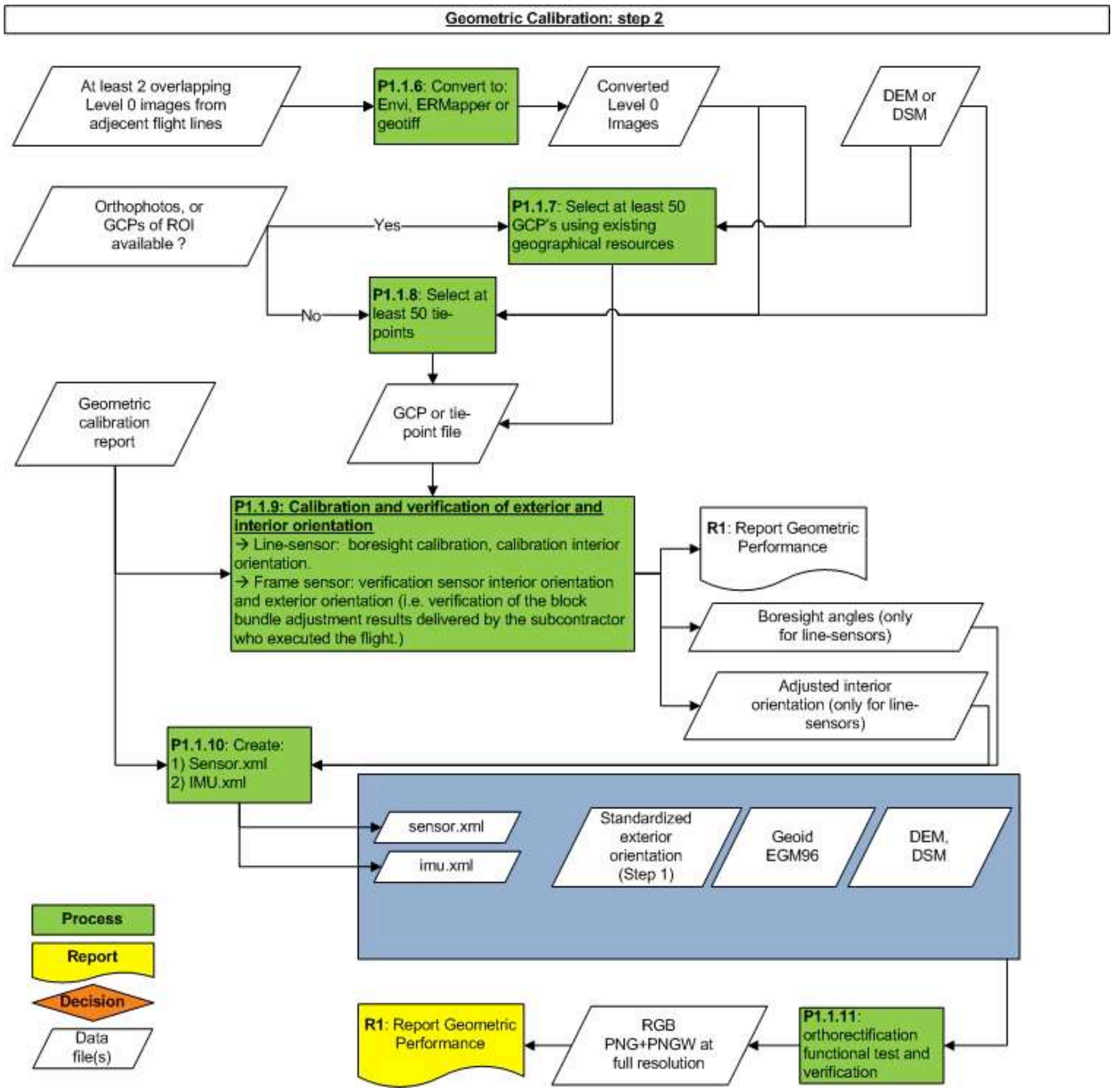

Figure 53. Processes involved in the geometric calibration (part 2).

Verification of the radiometric and spectral calibration

Figure 54 presents the processes involved in the verification of the radiometric and spectral calibration. Basically, this method is based on the transformation of in-situ measured ASD spectra towards at-sensor radiance by means of a C++ application responsible for the automatic configuration of the MODTRAN4 radiative transfer code. Unfortunately, the atmospheric composition during image capturing is often completely unknown. Furthermore, most of the atmospheric parameters are also variable both in the space and time domain. Therefore the C++ application performs a Monte Carlo simulation with respect to the most important MODTRAN4 atmospheric status/composition parameters. Note that depending on the application and sensor type (band settings) at hand, the list of uncertain MODTRAN4 parameters has to be customized to fit the objectives of the application.

Another very important parameter is "adjacency". This is the contribution of the background reflection in the observed target spectrum through atmospheric scattering. This adjacency effect is especially important in high resolution remote sensing and in regions with inhomogeneous surfaces (i.e. pixels with very different neighboring pixels with respect to their reflectance characteristics). The additive effect of adjacency can be simulated by taking into account a band-specific average radiation of some neighboring pixels. The uncertain parameter is thus the target-specific kernel size of the mean-filter applied on the image. This is also taken into account in the Monte Carlo simulation.

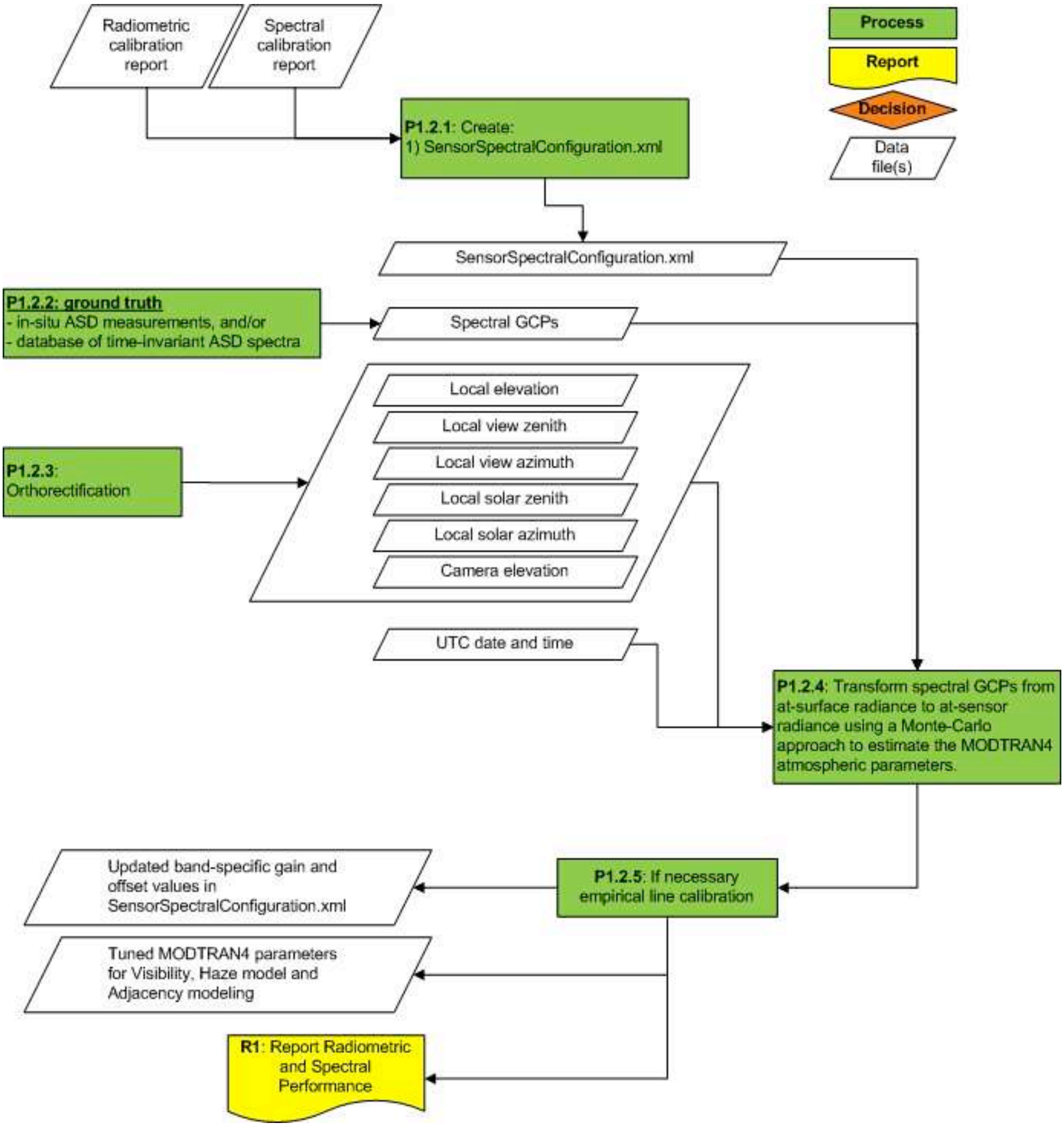

Figure 54. Processes involved in the radiometric and spectral calibration.

The result of the Monte-Carlo method is a set of MODTRAN4 parameters tuned for the image or block of images and a verification of the radiometric (gain and offset) and spectral (CW, FWHM, spectral response curve) calibration parameters.

If the at-sensor radiance spectrum of the transformed spectral GCP (i.e. the ASD measurement) does not correspond to the spectrum as measured by the airborne camera, this might indicate camera radiometric calibration problems. This can be partly solved by vicarious methods like the simple empirical line calibration (based on the spectral GCPs).

Spectral calibration problems can only be found if the camera has sufficient narrow bands near absorption features (O_3, water vapor, …). A solution for these problems is then ad-hoc elaborated.

The results of these verification actions are logged in report "R1" (Figure 55, Figure 54).

11.3.2 Archive data ingestion

The standard procedure of the VITO PAF for airborne remote sensing is to start from raw Level0 data. This Level0 image data and image meta data is then transformed to a Level1 HDF5 file having a standard format irrespective the airborne sensor type (multi- or hyperspectral whiskbrooms or pushbrooms, photogrammetric cameras). These Level1 HDF5 files form then the basis for (a) the Level1 to Level2 workflow (i.e. orthorectification and atmospheric correction) (b) the Level2 to Level3 workflow (i.e. the creation of seamless image mosaics), and (c) the Level2/3 to Level4 workflow (i.e. currently only the generation of GRB[1] change detection products).

A graphical representation of the archiving workflow is shown in Figure 56. This workflow is designed according to the Master/Worker pattern. The archiving master application permanently checks the (sensor specific) archiving input folder for a complete dataset. If such dataset is found, a new archive job is queued. Upon request of a worker node, the processing jobs are passed to that worker node. This workflow was designed to be used for near-real-time airborne disaster management applications (manned platforms or UAV systems), or satellite image processing services, which generated a constant stream of incoming data. The database update application continuously checks the archiving output folder for resulting "archive objects" (HDF5 files) and accompanying quicklooks, and inserts references to this archive objects in the database.

Starting from the input dataset, containing sensor data and metadata, positioning data and synchronization data, the worker then generates: (a) a standard Level1 HDF5 archive file, containing all information for further (Level2/3/4) processing and (b) a full or reduced resolution, orthorectified bitmap for fast visual data consultation (further referenced as "quicklook"). If the QL algorithms pass unit and integration testing, the worker applications can be updated to also generate additional quality layers such as (a) a haze/cloud mask and (b) a saturated pixel map. The Master application can be updated to also listen to specific quality layer metadata. These quality layers are then stored in the HDF5 image archive object.

The archiving process can be monitored by an operator through the remote workflow monitoring application. If a dataset fails to be archived, the operator can correct the problem and re-submit the dataset to the input folder system.

The "Success" folder is usually put on the archive storage disk arrays. Once registered in the database system, the dataset is thus immediately available for further processing or product distribution. Of course, before data references can be added in the database, all database tables involved in the definition of a mission and camera type have to be updated (mission table, product table, sensor table, …) and user or user-group access rights have to be defined. By default, no user is given access rights.

[1] GRB (Grootschalig Referentie Bestand): large-scale reference geographical vector database of civil structures (road infrastructure, buildings, parcels, waterways, …) created and maintained by AGIV (the Flemish Geographical Information Agency)

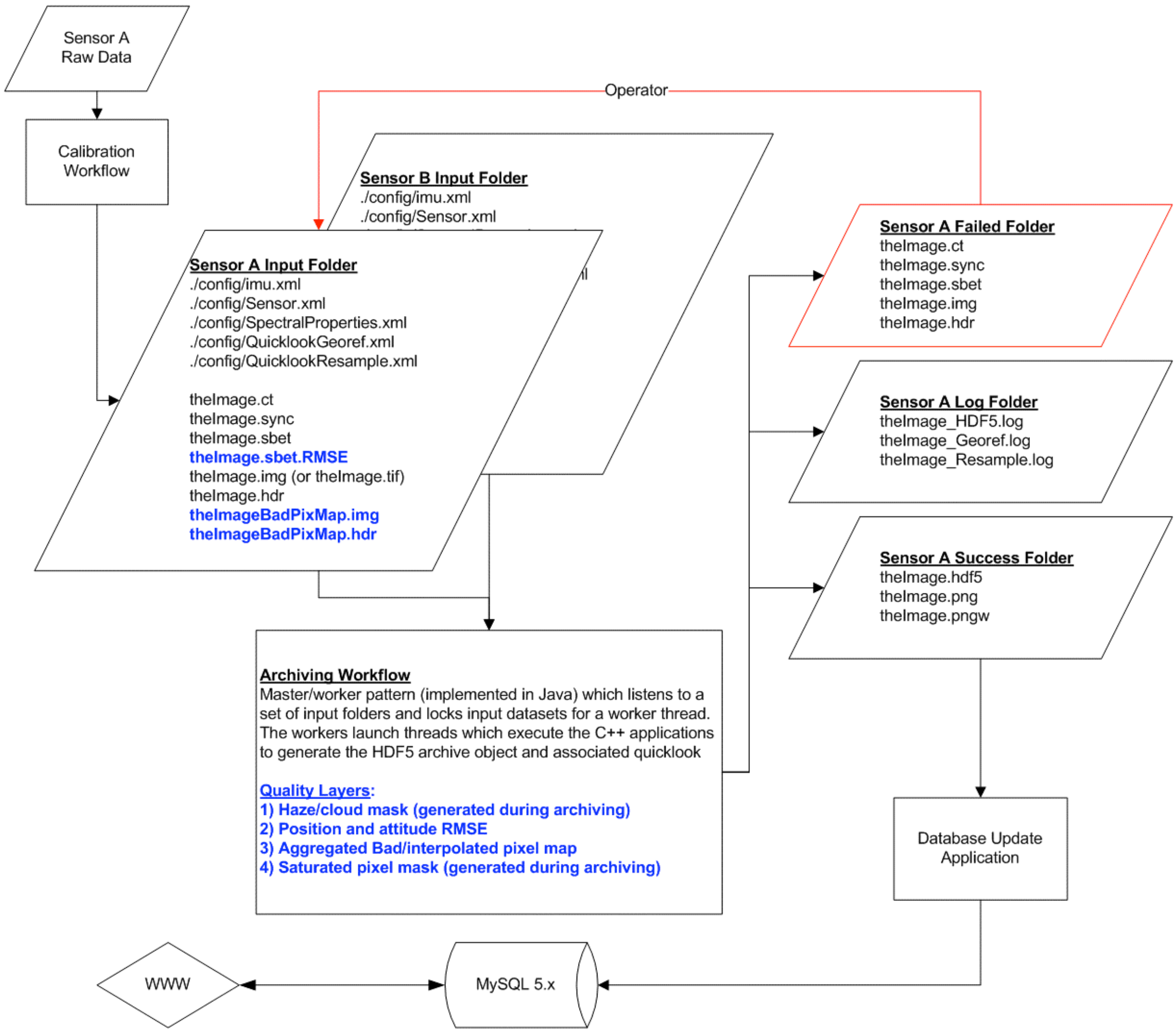

Figure 56. Functional flow archiving workflow. Blue items indicate the quality layers.

11.3.3 Level 1 to Level2 processing

The VITO level1 to Level2 processing workflow can be completely configured from within the WWW GUI (Figure 58). Depending on the user, specific processing algorithms may be enabled or disabled for configuration. As such, experimental algorithms can be included or excluded from the processing depending on the user-group or specific user.

Level1 to Level2 processing basically contains 2 major processes: geometric correction and atmospheric correction. Figure 58 also presents where the "quality layer" algorithms can be invoked.

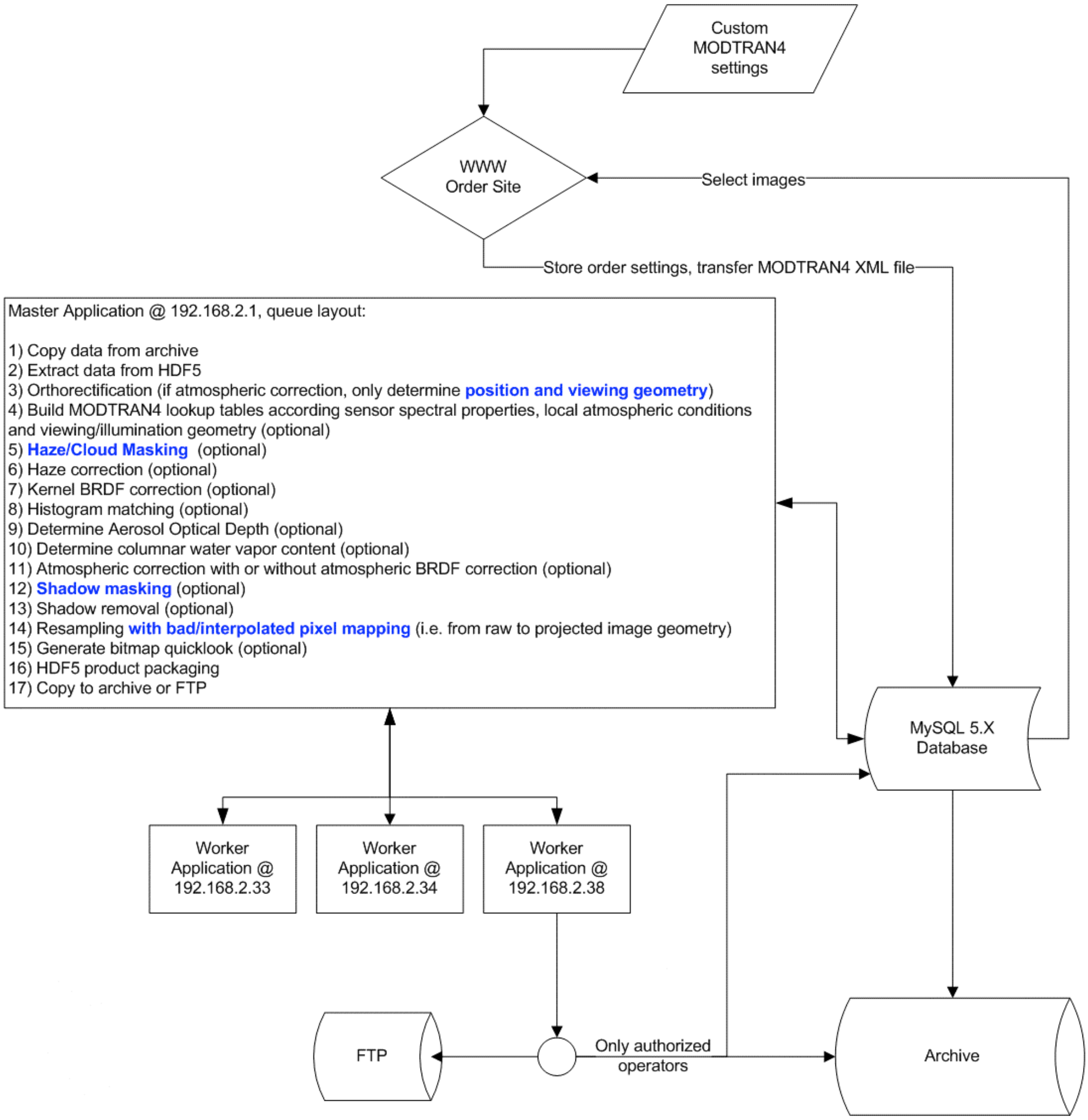

Figure 58. Layout of the Level1 to Level2 workflow. Blue items indicate the quality layers.

11.4 Examples for Quality Layers and Data Descriptors

As stated in section 11.3.1, the report labeled “R1” in Figure 55 will contain 3 sections:

1. The “Campaign Report” section will report about the 29 Common Data Descriptor QIs;
2. The “Geometric Performance” section will report about the geometric calibration verification results;
3. The “Radiometric and Spectral Performance” section will report about the radiometric and spectral performance.

As such, this report is an important interface with the user for providing the overall quality information associated with an imaging campaign.

The QL information will be optionally available in the Level1 or Level2 HDF5 products. The algorithms generation the QL information are all C++ programs.

On the condition that the relevant information is available, following QL information will be available in the Level1 product (optional layers in italic): (a) position and attitude RMSE values resulting from GPS/IMU time series Kalman filtering process, (b) *haze/cloud mask*, (c) bad/interpolated pixel map and (d) *saturated pixel map*.

If the needed algorithms comply the user and system requirements, following QL information will be available in the Level2 product (optional layers in italic): (a) *position, viewing and illumination geometry in raw sensor geometry*, (b) *haze/cloud mask in raw sensor geometry*, (c) *shadow mask in raw sensor geometry* and (d) *interpolated/bad pixels in projected geometry*.

Remark that this QL information will not be stored by default (the QL layers marked by italic font). Area-wide high resolution campaigns generate terabytes of raw data: to reduce archive storage volumes it will be ad-hoc decided whether or not the QL information will be stored in the HDF5 image product.

For HDF5 browsing, the reader is advised to download the tool "HDF viewer" from the "HDF Group" (see Figure 60). This is available at: http://www.hdfgroup.org/hdf-java-html/hdfview/ . This tool has also some editing capabilities.

For HDF5 information extraction, VITO supplies the "HDF5Reader" command line tool (windows & Linux). This tool was designed according following requirements:

- Metadata shall be extractable both in ASCII (data tables, XML files) or binary format (tables, pdf reports)
- Image data layers shall be extractable in GEOTIFF, ENVI, ERMAPPER, IDRISI, SURFER or ArcGIS raster layers. As of medium 2011, the JPEG2000 format will also be supported.

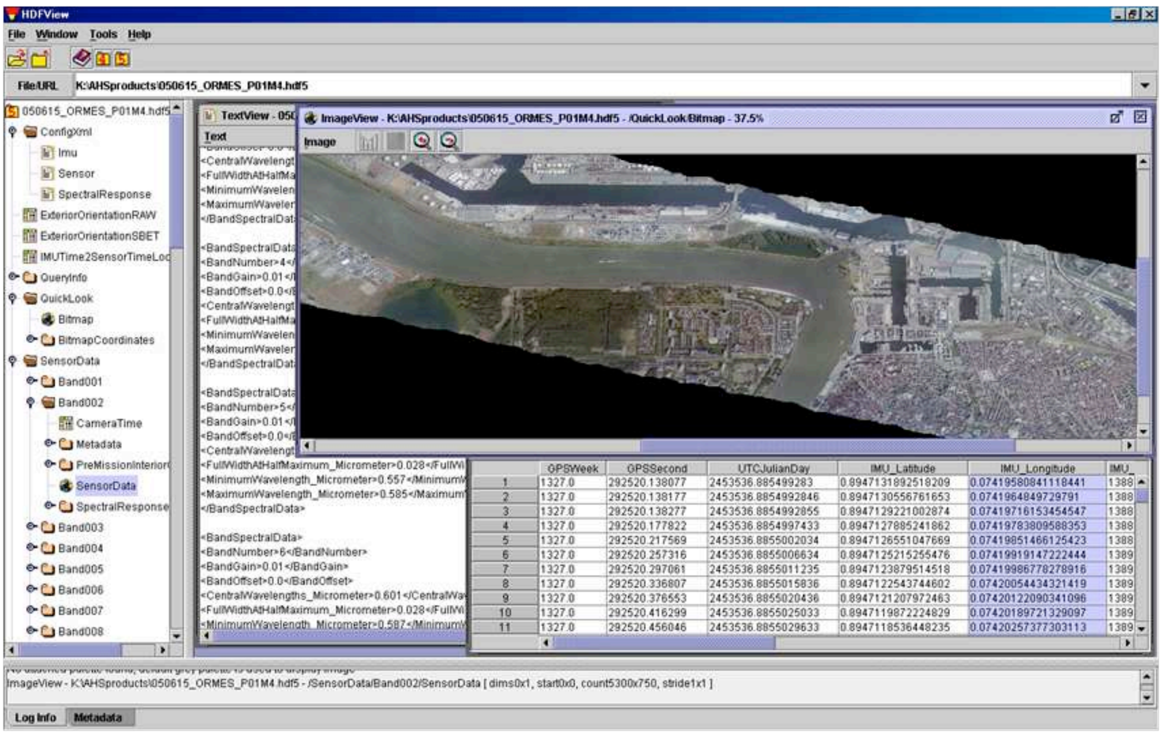

Figure 60. HDF5 browsing of a Level1 image (AHS160 hyperspectral sensor) using the "HDF

viewer" software.

12 Outlook on Testing and Validation (Task 3)

“Validation” is, according to its ANSI/IEEE definition, 'the process of evaluating a system or component during or at the end of the development process to determine whether it satisfies specified requirements'. “Testing” is thus an activity within the overall validation process.

Validation is therefore 'end-to-end' verification. Verification activities include:

- technical reviews, walkthroughs and software inspections;
- checking that software requirements are traceable to user requirements;
- checking that design components are traceable to software requirements;
- unit testing; integration testing; system testing; acceptance testing;

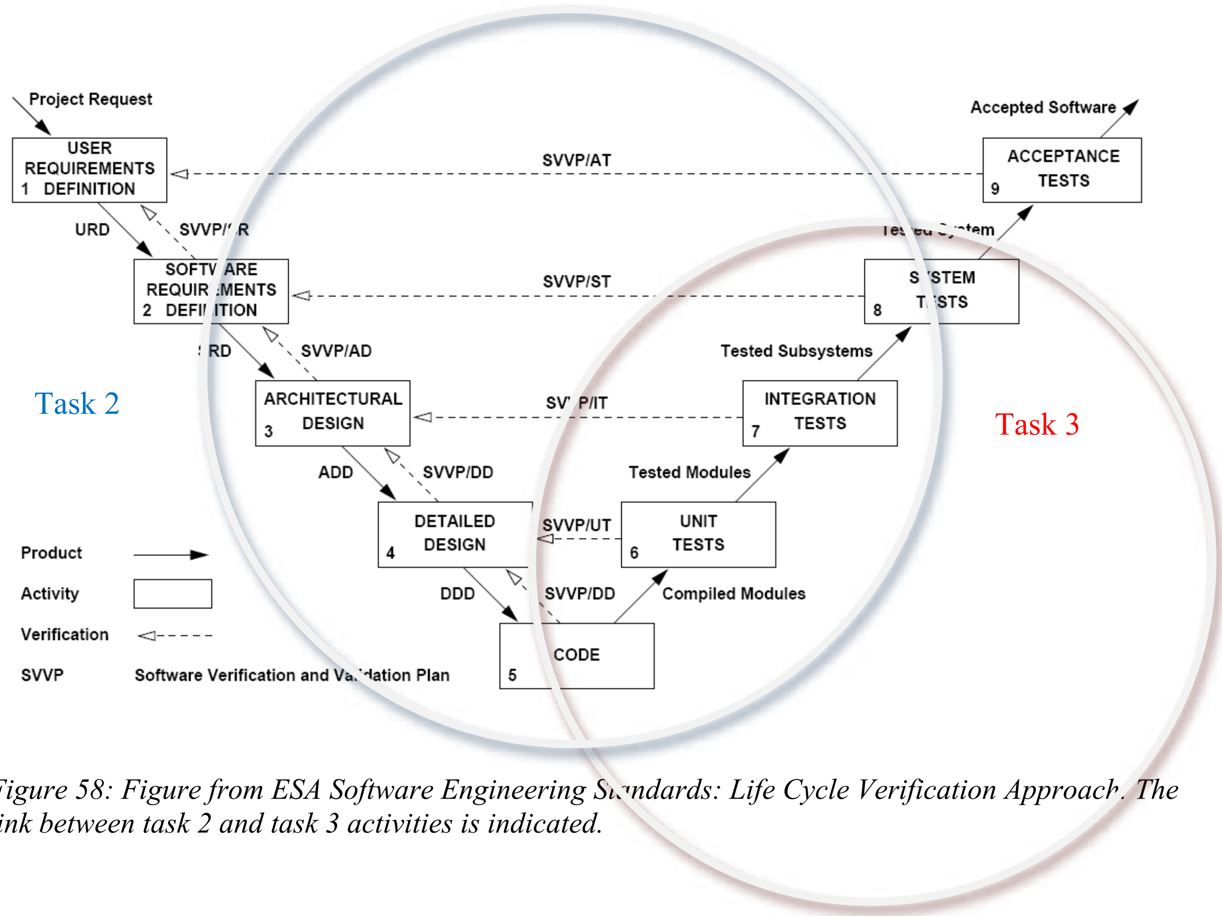

Figure 58: Figure from ESA Software Engineering Standards: Life Cycle Verification Approach. The link between task 2 and task 3 activities is indicated.

For each of the Quality Layers implemented in Task 2 (i.e. URD, SRD, ATBD and code is available and code is integrated in the processing workflows) the following tests are performed within Task 3 (**Error! Reference source not found.**) as detailed in the Software Verification and Validation Plan (SVVP) for each of the PAFs:

- **Unit tests** (UT) verify that the software subsystems and components work correctly in isolation, and as specified in the detailed design, by means of the SVVP/UT.

- **Integration tests** (IT) verify that the major software components work correctly with the rest of the system, and as specified in the architectural design, by means of the SVVP/IT.

- **System tests** (ST) verify that the software system meets the software requirements, by means of the SVVP/ST.

- **Acceptance tests** (AT) verify that the software system meets the user requirements, by means of the SVVP/AT.

In ESA terminology, „**unit testing**" refers to the process of testing modules against the detailed design. The inputs to unit testing are the successfully compiled modules from the coding process. These are assembled during unit testing to make the largest units, i.e. the components of architectural design. The successfully tested architectural design components are the outputs of unit testing. At VITO a Functional Test Framework (FTF) is continuously maintained (grouping of data, auxiliary data, configuration files, executables, logging and results) to test (a) module behavior according design and (b) to validate the ATBD.

This FTF is also being used for integration testing. For example, atmospheric correction involves a number of subsequent modules (creating MODTRAN lookup tables, image-based AOD retrieval, image-based water-vapor estimation, BRDF correction, land/water/cloud identification, the actual atmospheric correction). Once each module is unit tested, the series of modules can be integrated in a processing sequence that can be implemented in the FTF by means of a simple batch file. As such, the FTF can be used to validate the behavior and results of this module sequence, which thus functions as an integration test. However, because the VITO PAF is a distributed cluster computing system, part of the integration testing can only be executed after integration in the processing workflows and this to verify if the different modules are ready for cluster computing (synchronization, file access, etc…)

Finally, the system tests are focused on the verification of the SRD which was produced as an answer to the URD.

After passing the unit testing, integration testing and system testing, the ensemble of these tests has generated the necessary input for organizing a formal acceptance test. At VITO, it is preferred that the final acceptance tests are executed by the project partner who represent the user segment. And this is formalized by a project "acceptance review meeting". When an external partner is not available due to the given project consortium layout, an internal acceptance review meeting is organized.

For unit, integration and system testing, the HYQUAPRO common datasets can be used. VITO will use the Millingerwaard HYQUAPRO common dataset (i.e. AHS and HyMap data) acquired in a cross above land and water and containing cloud contaminated pixels.

The "EUFAR_QI_RequirementTraceability.xlsx" excel sheet (Common URD and PAF SRD) is used for requirement traceability. The test results will be logged in DJ2.3.1. (and later in DJ2.3.2). The testing and validation activities of quality layers in VITO, DLR , INTA and PML PAFs (USBE, TAU and FUB) will be described in DJ2.3.1. as follows (PAF specific):

1. **SVVP**: software verification and validation plan
2. **SVV activity results**
   - Unit test results
   - Integration and system test results
   - Acceptance test results

13 List of References

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14 ANNEX A – Product Level Specifications

Product Level Specification

Product Description	EnMAP	CEOS	Hyperion	EOS NASA	ESA
Raw time tagged data after restoration of the chronological data sequence, de-commutation and de-compression at a full space/time resolution including housekeeping and auxiliary information to be used in subsequent processing. Image tiling has been performed. Quality and screening parameters (e.g. cloud coverage and cloud distribution, bad pixels, healthy values) are added	not available for the user community	Level 0 Level 1a	Level 0	Level 0 Level 1a	Level 1a
The Level 1 product is radiometrically calibrated, spectrally characterised, geometrically characterised, quality controlled and annotated with preliminary pixel classification (usability mask). The auxiliary information (e.g. position and pointing values, interior orientation parameters, gain and offset) necessary for further processing is attached, but not applied.	Level 1	Level 1b	Level 1 R	Level 1b	Level 1b
The Level 2a product is derived from the L1 product and geometrically corrected (orthorectified) and re-sampled to a specified grid. Auxiliary data for further processing are attached, but not applied.	Level 2geo	Level 3	Level 1 GST	Level 3	Level 1c
The Level 2b product is derived from the L1 product, the data converted to ground surface reflectance values after atmospheric correction. Auxiliary data for further processing are attached, but not applied.	Level 2atm	Level 2		Level 2	Level 2a
The Level 2 product is derived from the Level 2a product, atmospherically and geometrically corrected and the data converted to ground surface reflectance values.	Level 2	Level 2 Level3	Level 2	Level 2 Level 3	Level 2a

Table 12: Product Level Specification

As no unique mapping of the different product level specifications is possible, the recommendation for EUFAR PAFs is therefore the usage of descriptive names such as L2atm for atmospheric corrected data.

15 ANNEX B – SRDs for the PAFs

15.1 SRD for DLR PAF

ID	Requirement Type	Requirement Origin	Requirement description
SRD_DLR_Functional_01	Functional	UR_001	For every airborne campaign, DLR shall produce a campaign report including basic characteristics of the sensor, the results of the vicarious geometric calibration (boresight calibration), vicarious radiometric CalVal, and the spectral CalVal. This report shall also include references to the procedures and related uncertainties according to EUFAR JRA2 DJ1.1.1. & DJ2.1.2.
SRD_DLR_DESI_01	Design & Implementation	UR_001	PAF-Specific: The campaign report shall be in accordance with the OpAiRS requirements for Campaign Reporting.
SRD_DLR_Validation_01	Validation	UR_001	Each integration test shall present an example "campaign report".
SRD_DLR_Functional_02	Functional	UR_002	The PAF-common QIs shall be produced and formatted irrespective of the sensor system.
SRD_DLR_Validation_02	Validation	UR_002	The validation tests shall be performed on imagery originating from HyMap and ROSIS.
SRD_DLR_DESI_03	Design & Implementation	UR_003	Each QI shall reference the units as part of the QI metadata. Unit-metadata shall propagate throughout the QI generation workflow(s).
SRD_DLR_Validation_03	Validation	UR_003	Integration test: the workflow validation tests shall report the QI metadata content to verify that QI-units are part of the QI metadata.
SRD_DLR_DESI_04	Design & Implementation	UR_004	The PAF-common QIs shall be implemented in accordance with the harmonized common Qis.
SRD_DLR_Validation_04	Validation	UR_004	Each integration / validation test shall generate a report reflecting the consistency in PAF-common Qis.
SRD_DLR_DESI_05	Design & Implementation	UR_005	References to EUFAR JRA2 Document DJ2.2.2. shall be given to document the Algorithm Theoretical Base. Additional references for DLRs PAF-specific QIs shall also be given.
SRD_DLR_Validation_05	Validation	UR_005	Each integration test shall provide a DLR campaign report to verify that the ATBD is referenced.
SRD_DLR_DESI_06	Design & Implementation	UR_006	For the product level definition, the "EnMAP" definition will be used as presented in ANNEX with the EUFAR JRA2 HYQUAPRO project document DJ2.2.2.
SRD_DLR_Validation_06	Validation	UR_006	Each integration test shall provide a DLR campaign report to verify that the level definitions are reported.
SRD_DLR_Functional_07	Functional	UR_007	Within the L0 / L1 / L2 processing workflows, a module shall be implemented which creates the 35 Common Data Descriptor QIs by parsing the corresponding log files.
SRD_DLR_DESI_07	Design & Implementation	UR_007	The text report containing the 28 Common Data Descriptor QIs shall be formatted in XML.
SRD_DLR_DESI_07	Design & Implementation	UR_007	Missing QIs which are part of the 28 Common Data Descriptor QIs, shall be marked as “No Information Available” in the text report.
SRD_DLR_Validation_07	Validation	UR_007	Each integration test shall provide a text report containing the Common Data Descriptors and shall be validated for

			completeness.
n.a.		UR_008	**Interpolated pixel mask not applicable for DLR PAF**
SRD_DLR_Functional_09	Functional	UR_009	Within the L0 / L1 / L2 processing workflows, a module shall be implemented which creates the Aggregated Bad Pixel Mask.
SRD_DLR_DESI_09	Design & Implementation	UR_009	PAF-Specific: The Bad Pixel Mask should include a land-water-mask as water is frequently marked as "bad" due to pixels with DNs close to zero (see DJ2.2.2). For this purpose an approach based on apparent reflectance thresholding is used.
SRD_DLR_Validation_09	Validation	UR_009	Each integration test shall provide a validation for L1 / L2 data products including the Aggregated Bad Pixel QL.
SRD_DLR_Functional_10	Functional	UR_010	Within the L0 / L1 / L2 processing workflows, a module shall be implemented which creates the Saturated Pixel Mask.
SRD_DLR_Validation_10	Validation	UR_010	Each integration test shall assess the provision and validation of L1 / L2 data products including the Saturated Pixel QL.
SRD_DLR_Functional_12	Functional	UR_012	Within the L0 / L1 / L2 processing workflows, a module shall be implemented which flags scanlines which have problems with position or attitude information.
SRD_DLR_DESI_12	Design & Implementation	UR_012	PAF-Specific: additional flags shall be generated indicating rapid changes in position or attitude (see DJ2.2.2).
SRD_DLR_Validation_12	Validation	UR_012	Each integration test shall assess the provision and validation of L1 / L2 data products including the Problems with Position / Attitude QL.
SRD_DLR_Functional_14	Functional	UR_014	Within the L0 / L1 / L2 processing workflows, a module shall be implemented which flags scanlines which have interpolated position / attitude.
SRD_DLR_Validation_14	Validation	UR_014	Each integration test shall asses the provision and validation of L1 / L2 data products including the Interpolated Position / Attitude QL.
SRD_DLR_Functional_16	Functional	UR_016	Within the L0 / L1 / L2 processing workflows, a module shall be implemented which generates cloud masks.
SRD_DLR_DESI_16	Design & Implementation	UR_016	For L1 data, this module is based on thresholds using apparent reflectances.
SRD_DLR_DESI_16	Design & Implementation	UR_016	For L2 data, the ATCOR cloud mask is used.
SRD_DLR_Validation_16	Validation	UR_016	Each integration test shall assess the provision and validation of L1 / L2 data products including the Cloud Mask QL.
SRD_DLR_Functional_17	Functional	UR_017	Within the L2 processing workflows, a module shall be implemented which generates cloud shadow masks.
SRD_DLR_Validation_17	Validation	UR_017	Each integration test shall assess the provision and validation of L2 data products including the Cloud Shadow Mask QL.
SRD_DLR_Functional_18	Functional	UR_018	Within the L2 processing workflows, a module shall be implemented which generates haze masks.
SRD_DLR_DESI_18	Design & Implementation	UR_018	PAF-Specific: the haze mask shall be part of the ATCOR HCW Haze-Cloud-Water mask.

SRD_DLR_Validation_18	Validation	UR_018	Each integration test shall assess the provision and validation of L2 data products including the Haze Mask QL.
SRD_DLR_Functional_19	Functional	UR_019	Within the L2 processing workflows, a module shall be implemented which generates information products allowing the user to identify pixels with critical viewing and illumination geometry.
SRD_DLR_DESI_19	Design & Implementation	UR_019	PAF-Specific: Based on ORTHO and ATCOR outputs, maps of the local view zenith & azimuth angles, a map of the local illumination, as well as solar zenith and azimuth angles for the scene shall be provided.
SRD_DLR_Validation_19	Validation	UR_019	Each integration test shall assess the provision and validation of L2 data products including the related QL products.
SRD_DLR_Functional_20	Functional	UR_020	Within the L2geo processing workflows, a module shall be implemented which generates a geo-location file.
SRD_DLR_Validation_20	Validation	UR_020	Each integration test shall assess the provision and validation of L2 data products including the geolocation file.
SRD_DLR_Functional_21	Functional	DLR_021	PAF-Specific: All modules related to the generation of QL and DataDescriptors shall be included in the DIMS-AIROS processing chain.
SRD_DLR_DESI_21	Design & Implementation	DLR_021	PAF-Specific: The implementation shall be in accordance to the OpAiRS guidelines for software development.
SRD_DLR_DESI_21	Design & Implementation	DLR_021	PAF-Specific: The SW modules shall interface with the existing SW modules.
SRD_DLR_DESI_21	Design & Implementation	DLR_021	PAF-Specific: The SW modules shall be documented in the OpAiRS SW documentation.
SRD_DLR_Validation_21	Validation	DLR_021	PAF-Specific: Each integration tesshall assess the validation of the processing chain for the generation of L0/L1/L2 data products.

Table 13: SRD for DLR PAF

15.2 SRD for INTA PAF

ID	Requirement Type	Requirement Origin	Requirement description
SRD_INTA_AHS_FUNC_001	Functional	UR_007	The IDL application A3 shall generate a text file (ASCII format) for each L1b image for reporting image quality descriptors (QD file)
SRD_INTA_AHS_DESI_001	Design & Implementation	INTA_001	The tool shall be executable for all images within the same "date" folder according to the INTA-AHS processing hierarchy
SRD_INTA_AHS_DESI_002	Design & Implementation	UR_004	The QD file shall follow a template to be provided as "custom furnished item"
SRD_INTA_AHS_DESI_003	Design & Implementation	INTA_002	The QD file shall be named as the parent L1b image but with suffix QD and extension txt, and will be located in the same folder of the parent L1b image
SRD_INTA_AHS_FUNC_002	Functional	INTA_003	The IDL application shall complete the template with the values reported >INPUT in the template, using the auxiliary files available under L1a and auxdata folders
SRD_INTA_AHS_DESI_004	Design & Implementation	INTA_004	It shall be possible to execute the tool several times for the same date folder; the tool will overwrite the output QD file each time it is executed
SRD_INTA_AHS_FUNC_003	Functional	UR_008 to UR_019	The IDL application A3 shall generate a QA file in ENVI BSQ format, data type unsigned integer (ENVI data type = 2)
SRD_INTA_AHS_DESI_005	Design & Implementation	INTA_001	The tool shall be executable for all images within the same "date" folder according to the INTA-AHS processing hierarchy
SRD_INTA_AHS_DESI_006	Design & Implementation	INTA_002	The QL file shall be named as the image but with suffix QAL, and will be located in the corresponding flightline subfolder of the folder QA
SRD_INTA_AHS_DESI_007	Design & Implementation	UR_004	The QL file shall have five bands named Number of saturated bands per pixel, BadPixel-Zero radiance count, Cloud Mask, Position Problem and Attitude Problem.
SRD_INTA_AHS_FUNC_003	Functional	UR_010	For each spectral band the tool shall detect saturated pixels according to the ATBD or import this layer from the one generated in AHS_rencpy
SRD_INTA_AHS_FUNC_004	Functional	UR_009	For each spectral band the tool shall detect pixels with a radiance less or equal than 0
SRD_INTA_AHS_DESI_008	Design & Implementation	UR_010	The tool shall write in pixel (i,J) of band #1 the number of bands in which pixel (i,j) is saturated or import this layer from the one generated in AHS_rencpy
SRD_INTA_AHS_DESI_009	Design & Implementation	UR_009	The tool shall write in pixel (i,J) of band #2 the number of bands in which pixel (i,j) has a negative radiance
SRD_INTA_AHS_DESI_010	Design & Implementation	UR_016	The tool shall write in band #3 the cloud mask according to the algorithm defined in section 8.2.3
SRD_INTA_AHS_DESI_011	Design & Implementation	UR_012	The tool shall write in pixel (i,J) of band #4 the problem/interpolated position according to the algorithm defined in section 8.2.1 and 8.2.2
SRD_INTA_AHS_DESI_012	Design & Implementation	UR_014	The tool shall write in pixel (i,J) of band #5 the problem/interpolated attitude according to the algorithm defined in section 8.2.1 and 8.2.2
SRD_INTA_AHS_DESI_013	Design & Implementation	INTA_004	It shall be possible to execute the tool several times for the same date folder; the tool will overwrite the output QAL file each time it is executed
SRD_INTA_AHS_FUNC_005	Functional	UR_019	There should be an application within A3 generating layers related to critical BRDF according to section 8.2.6

Table 14: SRD for INTA PAF

15.3 SRD for PML PAF

ID	Requirement Type	Requirement Origin	Requirement description
SRD_PML_DESI_001	Design & Implementation	UR_001, UR_003	ARSF produce campaign specific reports, along with yearly data quality reports and other publicly documentation. This fulfills the requirement for PAF-specific QIs and specification of assessment methods.
SRD_PML_FUNC_001	Functional	UR_002, UR_007	At the completion of processing, a program shall consolidate the output data descriptors, logs and other project information into an INSPIRE/ISO-19115 complicant XML metadata file and a text file.
SRD_PML_FUNC_002	Functional	UR_009	During L0 -> L1 processing, information will be output into the datacube and a matching mask as to which pixels are bad. These masks will be consolidated into an aggregated bad pixel mask at the completion of processing.
SRD_PML_FUNC_003	Functional	UR_010	A program will scan the L0 datacube to identify saturated pixels. This will be output as a mask indicating which pixels were affected by saturation. Additionally, for the Eagle sensor a datacube (and optionally an aggregated mask) will identify pixels affected by smear correction overflow.
SRD_PML_FUNC_004	Functional	UR_012, UR_014	During navigation processing, a vector will be produced that marks navigational problems as described in the common approaches section. Additionally, portions of the navigation with rapid movements will be marked.
SRD_PML_FUNC_005	Functional	UR_020	Geolocation (IGM) files will be produced for all relevant products.
SRD_PML_FUNC_006	Functional	UR_019	For L1 geolocated products, additional data layers detailing the view vectors of the aircraft to the ground and the relationship of the sun shall be provided.
SRD_PML_FUNC_007	Functional	UR_016, UR_017, UR_018	These URs are not satisfied in the PAF but do not meet the current delivery approach. They will be future developments if the opportunity arises.

15.4 SRD for VITO / UZH PAF

ID	Requirement Type	Requirement Origin	Requirement description
SRD_VITO_DESI_001	Design & Implementation	UR_001	For every airborne campaign, VITO produces a campaign report presenting the results of: (a) the geometric calibration (dGPS processing, boresight calibration, …) (b) the radiometric calibration, and (c) the spectral calibration. This report also explains the followed procedures, and can thus be considered as the PAF-specific QI-ATBD
SRD_VITO_VALI_001	Validation	UR_001	Integration test: present an example "campaign report" containing the results of: (a) the geometric calibration (dGPS processing, boresight calibration, …) (b) the radiometric calibration, and (c) the spectral calibration.
SRD_VITO_VALI_002	Validation	UR_002	The validation tests shall be performed on imagery originating from at-least two different sensor types.
SRD_VITO_DESI_002	Design & Implementation	UR_003	Each QI shall reference the units as part of the QI metadata. Unit-metadata shall propagate throughout the QI generation workflow(s).

SRD_VITO_VALI_003	Validation	UR_003	Integration test: the workflow validation tests shall report the QI metadata content to verify that QI-units are part of the QI metadata.
SRD_VITO_DESI_003	Design & Implementation	UR_004	Homogenizing PAF-common QI within all EUFAR PAFs means homogenizing on QI naming conventions and order of {T} bands. Since there are considerable different camera types, homogenizing does NOT mean that every PAF has to follow the same algorithmic procedures to calculate the PAF-common QI. with respect to the naming conventions, reference is made to the ATBD of the PAF-common QI's.
SRD_VITO_VALI_004	Validation	UR_004	Integration test: a validation test and associated validation report shall report on the naming conventions.
SRD_VITO_DESI_004	Design & Implementation	UR_005	Document DJ2.2.2. as part of the EUFAR FP7, JRA2 HYQUAPRO project shall document on the PAF-common QI Algorithm Theoretical Base. The VITO campaign report, presenting the results of (a) the geometric calibration (dGPS processing, boresight calibration, …), (b) the radiometric calibration, and (c) the spectral calibration shall describe the PAF-specific QI-ATBD.
SRD_VITO_VALI_005	Validation	UR_005	Integration test: provide a VITO campaign report to verify that the PAF-specific QI-ATBD is reported.
SRD_VITO_DESI_005	Design & Implementation	UR_006	For the product level definition, the "Enmap" definition will be used as presented in ANNEX with the EUFAR JRA2 HYQUAPRO project document DJ2.2.2
SRD_VITO_FUNC_001	Functional	UR_006	The extract scripts for the level2 HDF5 products shall use a naming convention as presented in ANNEX with the EUFAR JRA2 HYQUAPRO project document DJ2.2.2. Image cubes are thus named: HDF5name_L2_geo.img, HDF5name_L2_atm.img, HDF5name_L2_geo_atm.img
SRD_VITO_VALI_006	Validation	UR_006	Integration test: the validation report shall contain the content of the Level2 HDF5 dataextraction script to verify the naming convention of an extracted product is: HDF5name_L2_geo.img, HDF5name_L2_atm.img, HDF5name_L2_geo_atm.img
SRD_VITO_CONF_001	Software Configuration & Delivery	UR_007	The module which creates the text file containing the 28 Common Data Descriptor QIs shall be invoked in the L0-L1 Workflow. The resulting XML file shall be stored in the L1 product HDF5 container.
SRD_VITO_CONF_002	Software Configuration & Delivery	UR_007	The module which creates the text file containing the 28 Common Data Descriptor QIs shall be invoked in the L1-L2 Workflow. The resulting XML file shall be stored in the L2 product HDF5 container.
SRD_VITO_DATA_001	Data Definition & Database	UR_007	The text report containing the 28 Common Data Descriptor QIs shall be formatted in XML with associated XSD that will be used to validate the XML
SRD_VITO_DATA_002	Data Definition & Database	UR_007	If in the QI text files reference is made to external files (e.g. calibration reports, calibration data, …) these files shall be archived.
SRD_VITO_DATA_003	Data Definition & Database	UR_007	Time fields in the QI text reports shall be in UTC
SRD_VITO_FUNC_002	Functional	UR_007	A module shall be implemented which creates the text file containing the 28 Common Data Descriptor QIs by automatic polling the needed information from the PAF Database System.
SRD_VITO_INTF_001	Interface	UR_007	The information to create the text file containing the 28 Common Data Descriptor QIs shall be stored in the PAF database system.
SRD_VITO_OPER_001	Operational	UR_007	Upon new incoming data, an operator is responsible to update the database tables used to poll the 28 Common Data Descriptor QIs from.

SRD_VITO_QUAL_001	Software quality	UR_007	Missing QIs which are part of the 28 Common Data Descriptor QIs, shall be marked as "No Information Available" in the text report.
SRD_VITO_QUAL_002	Software quality	UR_007	Missing QIs which are part of the 28 Common Data Descriptor Qis and which are missing because the PAF database system is not up to data, shall be marked as "Not found in database system" in the text report.
SRD_VITO_SECU_001	Security & Privacy	UR_007	Sensor system information or image metadata that is not allowed for public dissemination shall be flagged in the PAF database system.
SRD_VITO_VALI_007	Validation	UR_007	Integration test: For a dataset already archived in the VITO PAF, the database and archive system will be updated with respect to the needed metadata to construct the text file containing the 28 Common Data Descriptor QIs by automatic polling.
SRD_VITO_DESI_006	Design & Implementation	UR_008	Quality Layer QI: Aggregated interpolated pixel mask (Pixel, L0, L1, L2). As part of the L0 to L1 calibration workflow and for pushbrooms: - A map shall be produced (if data available) indicating which of the defective CCD/CMOS pixels were interpolated. This shall be reported in the VITO "campaign report" as described in the SRD items in response of UR_001. The map of defective pixels is in CCD/CMOS geometry.
SRD_VITO_VALI_008	Validation	UR_008	Integration test: Verify interpolated pixel map of the CCD/CMOS in the campaign calibration report.
SRD_VITO_DESI_007	Design & Implementation	UR_009	Quality Layer QI: Aggregated bad pixel mask (Pixel, L0, L1, L2). As part of the L0 to L1 calibration workflow and for pushbrooms: - A map shall be produced (if data available) indicating which of the defective CCD/CMOS pixels were NOT interpolated and thus remain in the status "bad". This shall be reported in the VITO "campaign report" as described in the SRD items in response of UR_001. The map of defective pixels is in CCD/CMOS geometry.
SRD_VITO_VALI_009	Validation	UR_009	Integration test: Verify bad pixel map of the CCD/CMOS in the campaign calibration report.
SRD_VITO_CONF_003	Software Configuration & Delivery	UR_010	The module for generating the saturated pixel map shall be integrated in the L0 to L1 workflow, where it can be optionally invoked. The output is stored in the L1 product HDF5 file.
SRD_VITO_FUNC_003	Functional	UR_010	An algorithm shall be implemented to produce a saturated pixel indicator map (0/1) and this per spectral band and in raw sensor geometry. This algorithm shall be integrated in the Level0 to Level1 production workflow and can be optionally activated or deactivated.
SRD_VITO_VALI_010	Validation	UR_010	Integration test: perform a validation test of the Level0 to Level1 production workflow to verify the generation of the saturated pixel map.
SRD_VITO_CONF_004	Software Configuration & Delivery	UR_011	The module for generating the indicator map of pixels affected by saturation in the spatial/spectral neighborhood shall be integrated in the L0 to L1 workflow, where it can be optionally invoked. The output is stored in the L1 product HDF5 file.
SRD_VITO_FUNC_004	Functional	UR_011	An algorithm shall be implemented to produce a pixel indicator map (0/1) of pixels affected by saturation in spatial/spectral neighborhood, and this per spectral band and in raw sensor geometry.
SRD_VITO_VALI_011	Validation	UR_011	Integration test: perform a validation test of the Level0 to Level1 production workflow to verify the generation of the pixel indicator map (0/1) of pixels affected by saturation in spatial/spectral neighborhood.

SRD_VITO_FUNC_005	Functional	UR_012	For sensor systems dependent on the GPS/IMU solution for their georeferencing, problems with position information shall (a) be reported in the VITO "campaign report" as described in the SRD items in response of UR_001 and (b) shall be added as extra column in the SBET solution. This column will contain an indicator value (0/1). The SBET solution is stored in the Level1 product.
SRD_VITO_VALI_012	Validation	UR_012	Unit-test: validate the SBET production program to verify the production of position and attitude QI in the SBET table. This test is in response of UR_012, UR_013, UR_014, UR_015 and UR_016.
SRD_VITO_VALI_013	Validation	UR_012	Integration test: validate the L0 to L1 workflow to verify if the SBET table in the resulting L1 product has the additional columns for GPS/IMU QI. This test is in response of UR_012, UR_013, UR_014, UR_015 and UR_016.
SRD_VITO_FUNC_006	Functional	UR_013	For sensor systems dependent on the GPS/IMU solution for their georeferencing, interpolated position information shall: (a) be reported in the VITO "campaign report" as described in the SRD items in response of UR_001, and (b) shall be added in the column of the SBET solution reporting position problems (see also SRD items in response of UR_012). This column will contain an indicator value (0/1). The SBET solution is stored in the Level1 product.
SRD_VITO_FUNC_007	Functional	UR_014	For sensor systems dependent on the GPS/IMU solution for their georeferencing, problems with attitude information shall (a) be reported in the VITO "campaign report" as described in the SRD items in response of UR_001, and (b) shall be added as extra column in the SBET solution. This column will contain an indicator value (0/1). The SBET solution is stored in the Level1 product.
SRD_VITO_FUNC_008	Functional	UR_015	For sensor systems dependent on the GPS/IMU solution for their georeferencing, interpolated attitude information shall be reported: (a) be reported in the VITO "campaign report" as described in the SRD items in response of UR_001, and (b) shall be added in the column of the SBET solution reporting attitude problems (see also SRD items in response of UR_014). This column will contain an indicator value (0/1). The SBET solution is stored in the Level1 product.
SRD_VITO_FUNC_009	Functional	UR_016	For sensor systems dependent on the GPS/IMU solution for their georeferencing, synchronization problems shall be reported in the VITO "campaign report" as described in the SRD items in response of UR_001.
SRD_VITO_FUNC_010	Functional	UR_017	Quality Layer QI: Interpolated pixel during geocoding (Pixel, L2). This QI shall NOT be generated because it delivers no extra information since in the VITO PAF: - when the "nearest neighbour" interpolation sheme is chosen, none of the pixels are interpolated, - when a "distance weighted" interpolation sheme is chosen, all pixels are interpolated.
SRD_VITO_FUNC_011	Functional	UR_018	The code for atmospheric correction (as part of the Level 1 to Level 2 workflow) generates at-surface reflectance in the range of [0, 1] or at-surface radiance in [W/m²/µm/sr]. The code for atmospheric correction shall **not** truncate the output in the range of [0, 1] reflectance or associated radiance in order to allow detection of such problem pixels in certain spectral bands in subsequent higher-level processing modules.
SRD_VITO_FUNC_012	Functional	UR_018	If a pixel-dependent AOD (visibility) is used: store the used values in a separate grid. Invalid values shall be flagged as 1E-30. This grid is optionally added in the Level2 HDF5 product container.

SRD_VITO_FUNC_013	Functional	UR_018	If a pixel-dependent water vapor content is used: store the used values in a separate grid. Invalid values shall be flagged as 1E-30. This grid is optionally added in the Level2 HDF5 product container.
SRD_VITO_FUNC_014	Functional	UR_018	If a pixel-dependent viewing and illumination geometry is used during atmospheric correction: optionally store the view/solar zenith-angles and view/solar azimuth-angles in the Level2 HDF5 container.
SRD_VITO_FUNC_015	Functional	UR_018	The code for atmospheric correction shall dump a text file with the settings of all parameters used. If a parameter is pixel dependent, the associated grid shall be delivered and the text file shall mention "pixel dependent". The involved parameters are: the customized MODTRAN parameters (e.g. MODTRAN visibility, MODTRAN water vapor, MODTRAN IHAZE, MODTRAN O3, MODTRAN CO2, ...), the kernel width of the window to determine the background adjacency radiation, view zenith, view azimuth, solar zenith, solar azimuth, ground altitude, sensor system altitude. This text file is optionally added in the Level2 HDF5 product container.
SRD_VITO_VALI_014	Validation	UR_018	Unit-test: using the Millingerwaard AHS160 and HYMAP dataset for pixels with a resulting reflectance of bigger than 1.0.
SRD_VITO_VALI_015	Validation	UR_018	Unit-test: using a dark image (October, > 14:00 UTC) of the AHS160 sensor of the BELSPO 2007 campaign for pixels with a resulting reflectance of lower than 0.0.
SRD_VITO_VALI_016	Validation	UR_018	Integration test: impact analysis of not truncating the atmospheric correction output in the valid range of [0, 1] at-surface reflectance or associated radiance.
SRD_VITO_VALI_017	Validation	UR_018	Integration test: evaluate the resulting HDF5 products and the text file with atmospheric processing settings for following processing options: (1) all parameters fixed , (2) pixel dependent viewing geometry and (3) pixel dependent MODTRAN atmospheric condition parameters.
SRD_VITO_CONF_005	Software Configuration & Delivery	UR_019	The module for cloud detection shall be integrated in the L1 to L2 workflow, where it can be optionally invoked. The output is stored in the L2 product HDF5 file (in raw sensor geometry).
SRD_VITO_FUNC_016	Functional	UR_019	A module shall be designed and developed to automatically generate a cloud mask. The output shall be a probability or likelihood of being a cloud (no hard classification). The input can be one of the following: digital number, at-sensor radiance or at-surface reflectance or at-surface radiance. The module dumps an ASCII text file containing the percentage cloud cover at various cloud probability thresholds (50, 60, 70, 75, 80, 85, 90, 95).
SRD_VITO_PERF_001	Performance	UR_019	The cloud detection algorithm shall reach a completeness of better than 90%
SRD_VITO_PERF_002	Performance	UR_019	The cloud detection algorithm shall reach a correctness of better than 60%
SRD_VITO_VALI_018	Validation	UR_019	Unit test: the cloud mask method shall be tested on at least two different sensor types.
SRD_VITO_VALI_019	Validation	UR_019	Integration test: it shall be validated that a sensor-generic cloud mask can be generated in the L1 to L2 workflow.
SRD_VITO_CONF_006	Software Configuration & Delivery	UR_020	The module generating the cloud shadow mask shall be integrated in the L1 to L2 workflow, where it can be optionally invoked. The output is stored in the L2 product HDF5 file (in raw sensor geometry).

SRD_VITO_FUNC_017	Functional	UR_020	A module shall be designed and developed to automatically generate a cloud shadow mask. The output shall be a probability or likelihood of being a cloud shadow (no hard classification). The input can be one of the following: digital number, at-sensor radiance or at-surface reflectance or at-surface radiance.
SRD_VITO_PERF_003	Performance	UR_020	The cloud shadow detection algorithm shall reach a completeness of better than 90%
SRD_VITO_PERF_004	Performance	UR_020	The cloud shadow detection algorithm shall reach a correctness of better than 60%
SRD_VITO_VALI_020	Validation	UR_020	Unit test: the loud shadow mask method shall be tested on at least two different sensor types.
SRD_VITO_VALI_021	Validation	UR_020	Integration test: it shall be validated that a sensor-generic cloud shadow mask can be generated in the L1 to L2 workflow.
SRD_VITO_CONF_007	Software Configuration & Delivery	UR_021	The module generating the haze mask shall be integrated in the L1 to L2 workflow, where it can be optionally invoked. The output is stored in the L2 product HDF5 file (in raw sensor geometry).
SRD_VITO_FUNC_018	Functional	UR_021	A module shall be designed and developed to automatically generate a haze mask. The output shall be a probability or likelihood of being haze contaminated (no hard classification). The input can be one of the following: digital number, at-sensor radiance or at-surface reflectance or at-surface radiance.
SRD_VITO_PERF_005	Performance	UR_021	The haze detection algorithm shall reach a completeness of better than 90%
SRD_VITO_PERF_006	Performance	UR_021	The haze detection algorithm shall reach a correctness of better than 60%
SRD_VITO_VALI_022	Validation	UR_021	Unit test: the haze mask method shall be tested on at least two different sensor types.
SRD_VITO_VALI_023	Validation	UR_021	Integration test: it shall be validated that a sensor-generic haze mask can be generated in the L1 to L2 workflow.
SRD_VITO_CONF_008	Software Configuration & Delivery	UR_022	The module generating the maps of local slope and illumination angle shall be integrated in the L1 to L2 workflow, where it can be optionally invoked. The output is stored in the L2 product HDF5 file (in raw sensor geometry).
SRD_VITO_FUNC_019	Functional	UR_022	An algorithm shall be designed and developed for generating the local slope and illumination angle (in raw sensor geometry). Do not make a distinction between critical and non-critical areas with respect to critical topographic BRDF correction.
SRD_VITO_VALI_024	Validation	UR_022	Integration test: it shall be validated that the maps of local slope and illumination angle can be generated in the L1 to L2 workflow.
SRD_VITO_FUNC_020	Functional	UR_023	As a proxy for the Quality Layer QI "critical geometric correction based on DEM roughness" the VITO PAF shall store in the Level2 HDF5 product: - a map of the local slope (see SRD requirements in response of UR_022) - a map of the distance to the closest valid pixel produced during the resampling process (see SRD requirements in response of UR_008).
SRD_VITO_VALI_025	Validation	UR_023	Integration test: it shall be validated that (a) the maps of local slope and illumination angle and (b) a map of the distance to the closest valid pixel can be generated in the L1 to L2 workflow.

SRD_VITO_FUNC_021	Functional	UR_024	As a proxy for the Quality Layer QI "critical atmospheric/target BRDF geometry based on viewing geometry sun – sensor – terrain" the VITO PAF shall store (optionally) in the Level2 HDF5 product the full viewing and illumination geometry in raw sensor geometry: X, Y, Z, path length, solar zenith, solar azimuth, view zenith, view azimuth, local slope, illumination angle.
SRD_VITO_VALI_026	Validation	UR_024	Integration test: it shall be validated that the full viewing and illumination geometry (X, Y, Z, path length, solar zenith, solar azimuth, view zenith, view azimuth, local slope, illumination angle) can be optionally generated in the L1 to L2 workflow and stored in the Level2 HDF5 product.
SRD_VITO_FUNC_022	Functional	UR_025	The full positional information of every pixel (X, Y and Z) shall be optionally stored in the Level2 HDF5 product in raw sensor geometry.
SRD_VITO_VALI_027	Validation	UR_025	Integration test: it shall be validated that the positional information of every pixel can be optionally generated in the L1 to L2 workflow and stored in the Level2 HDF5 product.

Table 15: SRD for VITO / UZH PAF